THE

CATSKILL WATER SUPPLY

OF NEW YORK CITY

HISTORY, LOCATION, SUB-SURFACE INVESTIGATIONS AND CONSTRUCTION

BY

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PREFACE

In these days of rapid advance in engineering, one would look for considerable progress in the methods of construction during the building of the Catskill water works, especially when the magnitude of the work, the splendid engineering corps, and the variety of problems on the one hundred and twenty miles of dams, aqueducts, tunnels, etc., are considered. Here have been engaged, for many years, several hundred of the best engineers and scores of the best contracting firms, each with its own engineering and construction corps, and this in the most advanced section of the United States, with all the resources of the best makers of machinery to draw upon.

To enumerate a few of the most conspicuous and advanced features: Cyclopean masonry dams with concrete block facing and expansion joints, provided with drainage systems by which water is led harmlessly below and with wells and passages to permit inspection of the interior of the dam; the thorough aeration of the water; the building of cut-and-cover aqueduct employing steel forms, locomotive cranes, steam shovels, and central mixing plants, and the economical transporting of concrete over long distances; the excavation of circular shafts employing concrete lining instead of timbering and the perfecting of the method of controlling inflow of water through porous rock by grouting with cement; decided improvements in the speed and economy of sinking such shafts by a proper spacing of drill holes, use of hammer drills, steel forms, and concrete lining; improvements in the method of driving tunnels economically and close to ordered lines, and the employment of steel support in dangerous ground; the employment of deep tunnels under pressure to cross valleys and deliver water into the city, instead of steel pipes; decided improvements in the method, economy, and speed of lining tunnels with concrete, and the employment of steel forms on movable carriages;

bringing the same to a high state of perfection; decided advances in the method of taking care of water during placing of concrete lining in tunnels, so as to lead it harmlessly through pipes while the concreting is setting and later on grouting off same with cement, reducing the inflow to almost negligible amounts; improvement in the method of laying steel pipes and encasing them in concrete and lining with cement mortar to secure higher coefficient of flow and greater permanency. It is possible only to enumerate a few advanced features in this preface; the others will be found, it is hoped, in the body of the work.

To present the matter in reliable and readable form so as to give in the compass of a work not too long an adequate idea of the history, location, design, and construction of the work for the Catskill water supply is the aim of the author. If this be not accomplished, he alone is responsible, for no better opportunity could be wished for; having had direct contact by being connected with the work from almost its inception to its present nearly completed stage. The author was in charge of the location and construction of a most varied and difficult stretch at the upper end, and later of 9 miles of deep pressure tunnel at the lower end. He has enjoyed the cooperation of the other engineers in active charge with many sources of information open by the generosity of the Chief Engineer and the contractors.

Lastly, and indispensable, was the generous treatment of the publisher, Messrs. John Wiley & Sons, Inc., who have stinted in no way and helped in every way to make the book useful and desirable.

The author was encouraged to undertake this work so that a contemporaneous record of the great construction for the Catskill water supply should be made and published. This task was started late in 1911 with the expectation that it would be completed early in 1912, but such was the magnitude of the work that for anything like an adequate record it was necessary to put in an additional year of unremitting labor. The completion of this work would have been impossible were it not for the devoted assistance of Mr. Charles Goodman and the author's sister, Augusta. Mr. Goodman gathered from the various divisions of the work much of the available data, reports, etc., and assisted in their compilation, prepared tables and the index, wrote descriptions, read proofs, etc., so as to almost warrant having his name on the title page; in fact, multiplied the author's efficiency several fold. The author's sister gave several evenings a week for several months typewriting directly from dictation, and assisting in every way in the correction of proofs and smoothing out the English.

The time chosen for the preparation of this book was that of most active construction, the aim being to obtain information at first hand and, as far as possible, by direct contact with the work. In this the engineers of the Board of Water Supply heartily cooperated, checking up the author's manuscript in their offices, and afterwards the proofs which were sent out to the various divisions and departments of the work. The author believes that the peculiar merit of the book, if it has any, is that it was written, as it were, in the very atmosphere of the work and with the inspiration of daily contact with the directing engineers and contractors. This should have made it alive and totally different from the usual work written with either a superficial contact with the subject or from dead and fragmentary records.

Our Chief Engineer, J. Waldo Smith, encouraged the author to undertake this work and gave his helping hand throughout. This necessarily meant the cooperation of his great organization, for in many and subtle ways his spirit has inspired the force engaged upon this arduous work. Department Engineer Thaddeus Merriman has furthered the book by passing upon the proofs and offering suggestions and data for its betterment.

My colleague, Division Engineer J. P. Hogan, has contributed much to this work, both directly and by the stimulus of his energetic personality. The author is indebted to Robert Ridgway, formerly department engineer, for much material and for encouragement. Department Engineers Geo. G. Honness, Ralph N. Wheeler, Frank E. Winsor, and Walter E. Spear have also through their organizations assisted in many ways.

The various division engineers have all very kindly contributed much time to the furnishing of data, checking of proofs, etc., so that the author wishes to acknowledge his thanks to Messrs: S. F. Thomson, A. Thomson, Jr., Frank E. Clapp, Geo. P. Wood, Wilson Fitch Smith, Ernest W. Clarke, Chas. E. Wells, and B. H. Wait.

The author wishes to acknowledge his indebtedness to Mr. James F. Sanborn and Mr. M. E. Zipser of the Northern Aqueduct Department for their assistance, also to Mr. W. W. Peabody of the Southern Aqueduct Department, and to Mr. James F. Murphy, who has contributed much to the chapter on Contract 3; also to Mr. O. K. Myers, who has compiled much of the valuable caisson data given in Chapter XX.

The author is particularly indebted to the valuable publication, *The Catskill Water System News,* which appears bi-monthly. Such a publication is instrumental, in a work of this kind, in preserving much valuable contemporaneous information and in keeping up the interest of a large organization.

My assistant, Mr. R. W. Greenlaw, has given much time to correction of proofs, etc., writing a careful description of the construction of steel pipe siphons. Mr. Julian Richmond has aided much in the selection of the numerous plates and in other ways.

Much of the book is devoted to methods of construction employed by the contractors, but these are of interest to engineers in general, as design and construction should go hand in hand. Besides, engineers are more and more to be found in the ranks of contractors and changes from contracting engineers to supervising engineers and *vice versa,* frequently occur, so that there is no fear that these descriptions will not be of general interest. For information the author is directly indebted to Winston & Co., H. S. Kerbaugh, Inc., T. A. Gillespie Co., Degnon Construction Co., Elmore & Hamilton, King, Rice & Ganey, Pittsburgh Contracting Co., Grant Smith & Co. and Locher, and Holbrook, Cabot & Rollins, and indirectly through the engineers of the Board of Water Supply to all the other contractors.

For historical information used in the first chapter the author is indebted to Mr. Edward Wegman's "The Water Supply of the City of New York."

The author here wishes to rectify an omission: mention should have been made on p. 36 of the fact that the late Edmund J. Maurer was in general charge as Division Engineer of all the engineering work connected with real estate, and rendered signal service.

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CATSKILL WATER SUPPLY

CHAPTER I

HISTORY OF NEW YORK WATER WORKS

Supply 1613 to 1774. The Dutch found Manhattan a well-watered island, traversed by many brooks abounding in fish; with a large fresh-water pond, known as the "Collect," fed by numerous springs. The lower part of the island was underlaid with sand which readily yielded fresh water a few feet above sea level, but the upper part was mostly hilly and rocky, with little water.

The population of the island by 1664 was but 1500, and water was obtained from private wells, although about 1658 a public well was dug near Bowling Green. Later, public wells were dug systematically at the street corners by the Aldermen and Select Councilmen of New Amsterdam. Very soon, however, as the town grew, the wells became contaminated and the supply of water insufficient. Those who could afford it sent for water from distant wells. One well in particular, known as the "Tea-water Pump," was particularly noted; so that its neighborhood became so congested with water-carts that the spout of the pump was raised and lengthened to permit pedestrians to pass under it. This well was located near the site of the notorious "Five Points" at Chatham Square.

By 1774 the population had increased to about 30,000, and the City was confronted by a shortage of water, a condition which from that time to this has only been temporarily relieved; for it has always been that soon after the City settled down with the comforting assurance that the new supply would be all that could be desired, the growth of population and demand again created a shortage of water.

The first water works were begun shortly before the Revolution by Christopher Colles, an English civil engineer, who aimed to pump water from wells and the Collect through hollow logs to a reservoir at Broadway and White Street, employing an old Newcommen engine. It was intended to pay for the work with paper money, some notes of which are still in existence. However, the Revolution put a stop to this.

Revolution to 1830. After the Revolution, the population having increased to 60,000 by 1800, the need for more water was greatly felt, and the town was spurred on to secure a new supply by the ravages of yellow fever. After fruitless discussion, the Manhattan Company, formed by Aaron Burr, was chartered to supply water and incidentally to employ its surplus capital in moneyed operations.

Aaron Burr's Manhattan Bank Supply. The history of New York City's earliest water works is associated with a most interesting period in the politics in the State and country, and with two of its most notable characters—Alexander Hamilton and Aaron Burr. New York was then, and in fact remained until the introduction of Croton water, as described by an early writer, "a city most destitute of the blessings of good water." In 1799 the Federalists controlled the legislature of the State and the only banks in New York. Hamilton, the great leader of the Federalists, was a director of the bank of New York, the oldest in the State. Aaron Burr was the leader of the Republicans, afterwards the Democrats. Burr and his associates were anxious to secure a franchise for a bank, which was denied them. They organized the Manhattan Company, which was duly incorporated by the legislature in 1799, ostensibly for the purpose of bringing water from the Bronx River. But they secured the insertion of the following clause:

> "and be it further enacted that it shall and may be lawful for the said company to employ all such surplus capital as may belong or accrue to said company, in the purchase of public or other stock, or in any other monied transactions or operations not inconsistent with the Constitution and laws of this state or of the United States, for the sole benefit of said company."

This generous joker gave the company power to conduct any lawful business, and it soon availed itself of this privilege by opening a bank still in existence as the "Bank of the Manhattan Company" at 40 Wall Street. Instead of going to the Bronx River, it did the easiest possible thing, constructing an iron water tank near the Collect Pond and pumping from a well with two 18-H.P. steam engines. From this place wooden pipes consisting of bored-out logs were laid through the lower part of the city. They are still occasionally dug up in the subway constructions, many of them still in a fair state of preservation. Although twenty miles of these mains were laid, supplying 1400 houses, the service rendered by the Manhattan Company was very poor in quality and quantity (700,000 gals. per day). It remained, however, the only considerable supply until water was brought to the city by the old Croton aqueduct, after which time the service of the Manhattan Company was only nominal and consisted in keeping its old tank full or partly full of water. This tank is still in existence, boxed up in a four-story building at the corner of Reade and Center Streets, and is still supplied with water. Its career will soon be ended, as the property is to be condemned, together with a large adjacent area, for a new monumental court house recently decided upon. The Manhattan Company is still a powerful institution.

First Public Water Supply. The first public water works were constructed about 1830. It consisted of an elevated tank of about 230,000 gallons capacity supplied by a steam engine of 12 H.P., which pumped from a well at Thirteenth Street and Broadway. There was quite a shaft, 16 feet in diameter and 112 feet deep, with two horizontal galleries, each 75 feet long, near the bottom, 98 feet of the shaft being in solid rock. Its daily yield was 21,000 gallons, but the water, which was originally soft, deteriorated. From this well cast-iron mains, 6 inches to 12 inches in diameter, were laid and by 1833 a total of about seven miles were placed.

How inadequate the scource of supply first utilized by the city must have been is demonstrated by the results of sinking the Manhattan shafts of the City Aqueduct. The shaft for the first water supply was about the same diameter as those of the Catskill Aqueduct. Shaft 18 at Twenty-fifth Street and Broadway yielded at the depth of 100 feet, about 20 gallons per minute, or 30,000 gallons per day. Shaft 19 at Sixth Street and Fourth Avenue, yielded only about 2000 gallons per day at 100 feet in depth. Other shafts on Manhattan yield from 0 gallons to 20 gallons of water per minute.

This first municipal supply proved entirely inadequate, and numerous plans were proposed for new supplies, the city being spurred on by the example of Philadelphia, which previously had secured an ample supply of about two million gallons per day from the Schuylkill and had thereby conquered the yellow fever, from which New York was suffering severely. Philadelphia was also advancing rapidly as a city and threatened to outstrip New York in commerce.

Proposed New Supplies. The Croton supply was first proposed in 1830, but seemed a far distant source compared to others proposed, such as the Bronx River and Rye Ponds. No progress was made, as proper authorization was not secured from the legislature. In 1832 cholera ravaged the island and impelled the citizens to renewed efforts. As early as 1798 the dangerous character of Manhattan Island water was pointed out, and in 1832 the Common Council reprinted and distributed reports to that effect. Yet it is remarkable how persistently the people clung to their old wells. The last of them were banished from the island by the Board of Health a few years ago.

The first real progress was made when in 1832 Col. De Witt Clinton was engaged to examine the various sources and routes of water supply thus far suggested. In a little over a month he reported and showed the most enlightened comprehension of the problem:

" With such evidence of an augmenting and multiplying wealth and population in the increase of her ships, her manufacture and the permanency and splendor of her public and private dwellings, and with the most conclusive evidence from her geographical position, and her proximity to the ocean, and the security of her harbor, that she be to this country what London is to England, it must be a matter of profound regret that she is destitute of a supply of good and wholesome water and that there should exist any hesitation to grant her power to obtain an element so essentially connected with the property, health and comfort of her citizens."

To show how costly an inadequate supply of water is, Clinton estimated that about $270,000 was paid annually for water in hogsheads hauled from remote springs, and that the shipping paid, in addition, $50,000 for water supplied from Long Island and New Jersey, not daring to use New York water. Many ships even carried enough water in casks to last them for the journey back to their ports to save this charge.

Col. Clinton's Croton Project. Col. Clinton estimated that the Croton River could supply 20,000,000 gallons per day by natural flow, and estimating only a consumption of 20 gallons per day per person, stated that this would make the Croton River a sufficient source for a long time. He recommended a low dam, near the location of the old Croton dam, to turn the natural flow directly into an aqueduct built on grade all the way to New York. The route he suggested was that followed later in the construction of the old Croton Aqueduct.

The Croton scheme was strongly opposed by many people, particularly by those who thought artesian wells could yield a sufficient supply, and others who thought the Bronx River was an adequate source. A company was promoted known as the Rockwater Company which proposed to drill wells, and advanced the following argument:

"By thus supplying the inhabitants with fine, pure rock water it will remove the popular pretext for using alcohol to correct the impurities of the water now in general use, and will be the most effectual means of promoting the great and noble cause of temperance in this city."

Even at this time, however, it was known that Manhattan Island was ill adapted to yield artesian water, as the water hitherto found in deep wells proved both deficient in quantity and quality.

First Act for New Water Supply. In 1834 the Legislature of New York passed "An act to Provide the City of New York with Pure and Wholesome Water." Ever since, all the water legislation starts with the same formula.

The first water commissioners engaged Maj. D. B. Douglas of the United States Military Academy to make surveys and investigations. He examined both the Croton and the Bronx Rivers and reported decidedly in favor of the former. He estimated that the Bronx River could supply only about six million gallons per day.

Old Croton Dam. The first adequate water works for New York City was constructed between 1837 and 1842. To form a reservoir an overflow weir, known as the old Croton Dam, was built about six miles above the mouth of the Croton River. This dam was of very peculiar construction, being founded on rock-filled timbered cribs placed in the bed of the stream and only partly on ledge rock. On these cribs ashlar granite masonry was laid up to form an ogee curve of about 55 foot radius. The maximum height of the dam was thus about 50 feet, about 240 feet of its width forming a spillway, with its crest at an elevation of about 166.2 feet, Croton datum. A secondary crib dam 300 feet downstream from the apron of the main dam was built to form a water cushion and prevent erosion of the toe of the dam; also to break the fall of the water into two parts, 33 feet and 15 feet respectively. Above the masonry dam was a long slope, about one in five, paved with heavy riprap. This dam served its purpose perfectly until the New Croton Dam was put in commission in 1907. Continuous records have been kept of the flow over the dam, so that we have complete records of the Croton River for over forty-five years. Very heavy floods have repeatedly passed over the dam; in 1854 there was 8 feet of water on its crest and the secondary dam was washed out, creating considerable alarm at the time. Other floods at times have washed great holes below the secondary dam, which has had to be repaired frequently. It is probable that without the protection of this secondary dam the main dam would have been washed out.

Old Croton Aqueduct. The old Croton Aqueduct has a cross-section of only about 53 square feet and is horseshoe shaped, 8′ 5″×7′ 5″. The aqueduct follows mainly the surface of the ground along the bank of the Croton River to the Hudson, thence along the Hudson to Yonkers; thence along the ridge between the Hudson and East Rivers to High Bridge, crossing the Harlem River at this point on high masonry arches built in the style of the old Roman aqueducts. This aqueduct bridge is 1450 feet between gate houses, and consists of fifteen semi-circular arches. Eight 80-foot spans, and seven 50-foot spans. Soffit of arch is 100 feet above high water. Four of the piers are founded on rock; others on cofferdams sunk as low as 54 feet below tide. It was first proposed to build this bridge to hydraulic grade, which would have made it many feet higher. In order to save expense it was left low and on the top of it two 36-inch pipes were laid. In 1860 a wrought-iron pipe 7 feet 6½ inches in diameter was added, the side walls raised up and roofed over, as it now appears. The pipe is still in a very good state of preservation. The cost of High Bridge was about $1,000,000. It is to-day almost perfect, showing no signs of deterioration and is probably the finest piece of masonry in the vicinity of New York.

After crossing High Bridge the aqueduct follows along Tenth Avenue to 108th Street, crossing the Manhattan valley in a line of two 36-inch pipes, thence in a masonry conduit to the Central Park receiving reservoir. Though the city between Eighty-fifth and 108th Streets had been long mapped and the present street system adopted, the first water commissioner thought there was very little likelihood of this portion of the city being built up, and he constructed the ordinary type of aqueduct diagonally across the street system, leaving a few archways for certain streets to pass through. However, by 1865 the city had grown up into this neighborhood, and by legislative act it became necessary to remove this portion of the aqueduct. It was replaced by two lines of 6-foot cast-iron pipes 1⅜ inches thick. For some reason these pipes gave a great deal of trouble, frequently splitting at the hubs, and finally had to be replaced by three lines of 4-foot pipes.

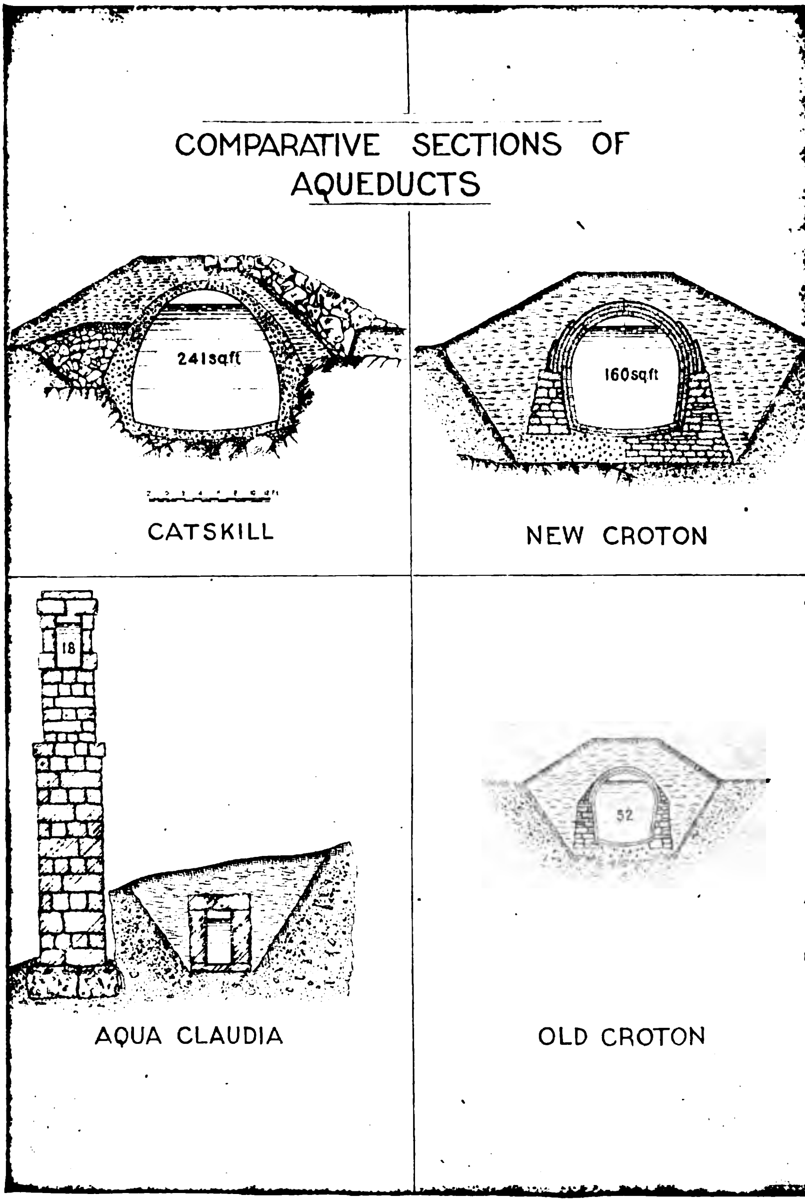


PLATE 1.—Comparative Sections of Ancient Roman, Croton, and Catskill Aqueducts.

The grade of the aqueduct is 13¼ inches per mile; for the Harlem and Manhattan siphons 2 and 3 feet extra head were used up. Later, to draw more water from Croton Lake the upper five miles of the aqueduct was depressed to a grade of six-tenths of a foot per mile, to gain about 3 feet of storage. There are sixteen short tunnels on the old aqueduct, 160 to 1263 feet long, aggregating 6841 feet. There was a limited appropriation for the construction of this aqueduct, so that it was necessary to be economical in its design. A great deal of the aqueduct has been built on loose rock fills and the slopes in the embankments are very steep, often being held by dry rubble walls.

Consumption of Croton Water after 1842. Upon the completion of the first aqueduct it was estimated that a liberal per capita consumption would be 22 gallons. As the population was then but 300,000, and the capacity of the aqueduct was estimated at 72 to 95 million gallons per day, it was thought that it would be able to supply water to the city for a long time to come. It was found, however, that 22 gallons was far from sufficient, as the people learned to use water lavishly; by 1850 the per capita consumption was 90 gallons. Twenty-five years after completion the aqueduct was running at more than its maximum safe capacity.

On some of the high embankments the aqueduct had settled considerably. To get water by these depressions it was necessary to put the aqueduct under pressure. At these embankments many longitudinal cracks opened in invert and arch. Every year extensive repairs were made, the aqueduct being drained for a few days and reinforced by additional rings of brick and by grouting the cracks. In 1885 an extensive break occurred at Van Cortlandt Park, necessitating shutting off the aqueduct for several days, during which time the water in the Central Park Reservoir was almost drained down.

It was early found that the old receiving reservoir of 180,000,000 gallons capacity, and the Murray Hill distributing reservoir of 24,000,000 gallons at Forty-second Street and Fifth Avenue, whose site is now occupied by the Public Library, were entirely inadequate to supply the city, particularly at times when the aqueduct was out of service.

Central Park Reservoir. Between 1857 and 1862, the new Central Park reservoir of 1000 million gallons capacity was constructed. The basin for the new reservoir was made by excavating between natural hills and building embankments. These embankments have puddled core walls, and slopes of 1½ to one, the interior slope being paved with large cemented blocks and the outer slopes sodded. The reservoir has a water surface of 96 acres and a maximum depth of 38 feet. This reservoir is of much greater capacity than the former one was and has been of great service to the city, particularly up to the time of the completion of the new Croton Aqueduct.

High Bridge Reservoir. A considerable settlement sprang up in the neighborhood of Washington Heights at quite an early period. This district, being above the level of the Croton Aqueduct, had to be supplied with a high-pressure service. In 1869 a new reservoir was built at the Manhattan end of High Bridge, which has a water surface elevation of 216 feet, with a capacity of 10 million gallons. A still higher district is supplied from the water tower of 47,000 gallons capacity, elevation 324 feet. To supply this reservoir and tower some large pumps were installed.

Shortage of Water 1869, 1876, 1880, 1881. In 1869 there were only four storage reservoirs which could be drawn upon for water, viz., the original Croton Lake, the old receiving reservoir in Central Park, the new Central Park Reservoir, and the Murray Hill Reservoir. These had a combined capacity of only 1804 million gallons. The rainfall that year and the next was very small, so that all the reservoirs were emptied and only the natural flow of the Croton River available, estimated at about 30 million gallons per day, ordinary flow. Luckily there were many natural lakes and ponds in the watershed. Drastic measures were taken and the outlets of these ponds deepened, so that they were drawn upon for 2000 million gallons. The Boyd's Corner Reservoir was put in service in 1873, and holds 270 million gallons.

Nevertheless, in 1876–1877, the city again suffered from drought and was confronted with a shortage of water. By special legislative enactment the city secured permanent rights to draw water from available lakes in the watershed, these rights being appraised by condemnation. This met with violent opposition from the property owners, particularly those who owned estates along the shores, as some of these lakes are picturesquely located among the hills. Middle Branch Reservoir on the Croton River, completed in 1878, added 4000 million gallons to the storage supply, making a total storage of about 8000 million gallons. But, again, in 1880–1881, the two driest years on record, all the reservoirs were emptied, and the natural flow of the Croton River dropped down to 10 million gallons daily. It was necessary to throttle the supply and great hardship was the result. Some new ponds were again drawn upon and the situation saved.

Bronx and Byram Supply. In order to secure a supply for the portion of the city, then recently annexed, lying above the Harlem River, the Bronx and Byram Rivers were drawn upon in 1884, and a reservoir was created by the construction of the Kensico Dam, having a storage capacity of 1620 million gallons. The area of watersheds of the Bronx River and Byram combined is only 22 square miles. The conduit is a 48-inch pipe, 15.2 miles long, from Kensico Lake to Williamsbridge Reservoir. This supply was first proposed in 1798 and then deemed sufficient to supply the whole city of New York for a long period. The Bronx system, though supplying only a small amount of water, has proved to be of great value through the Kensico Reservoir, which is to be greatly enlarged to form an essential part of the Catskill water system.

New Croton Reservoirs. In 1892 the East Branch, Sodom and Bog Brook Reservoirs added a total of 9000 million gallons to the storage supply.

Many of the low dams commonly built in the Croton system are of earth with masonry core walls on rock or hardpan, but supplied with ample masonry spillways. This type of dam is economical in construction, and, if provided with ample length of spillway, is safe. None of the dams of this type in the Croton system has failed.

Shortage of Water in 1880. By 1880 the population of the city had increased to 1,212,000, but the water supply had remained constant for a long time, the average amount supplied by the Croton Aqueduct being 86 million gallons and the Bronx 16 million gallons. This was entirely insufficient for the city, it being estimated that 45 million gallons more per day would have been used had the supply been sufficient. This shortage of water necessarily caused low pressures and much pumping to secure water at the upper stories of the houses, the day pressure being reduced to the first- and second-story level in many parts of the city, with many mains throttled to reduce pressure and check consumption.

New Croton Aqueduct. In 1882 Isaac Newton, Chief Engineer, proposed that a new aqueduct be built to supply 250 million gallons per day, that it be constructed entirely in tunnel (12 feet in diameter) with an inverted siphon under the Harlem River. To aid in its construction, 35 shafts were to be sunk. For additional storage a great dam was to be built at Quaker Bridge, a few miles below the old Croton Dam. This plan met with so much favor that, at the request of the legislature, the Mayor appointed a citizen's committee of three men to report on this project. Their report was entirely favorable, but they recommended a larger aqueduct, 15 feet in diameter, the construction of new storage reservoirs and a new Croton Dam. Accordingly on June 1, 1883, the legislature passed "An act to provide new reservoirs, dams and a new aqueduct for the purpose of supplying the city of New York with an increased supply of pure and wholesome water."

Croton Aqueduct Commission. The first commissioners were James C. Spencer, G. W. Lane and William Dowd, but the commission was subject to numerous changes due to new city administrations and changes of law. The first Chief Engineer, B. S. Church, was succeeded by Alphonse Fteley, who is to be credited with the bulk of the work on the new Croton Aqueduct. He was succeeded by William R. Hill and J. Waldo Smith. The construction began in January, 1885, and water flowed into the Central Park Reservoir in July, 1890. The contract for the Croton Dam was awarded in August, 1892, and the dam was completed in 1907. The contract for the Jerome Park Reservoir was awarded to J. B. McDonald, and the west basin was put in service in 1906.

New Croton Aqueduct Location. The New Croton Aqueduct, except for a little over a mile in deep open cut, is entirely in tunnel from Croton Lake to 135th Street, the terminal gate house, a distance of over 33 miles. This was and probably still is the longest continuous tunnel in existence, though, of course, none of the headings is of great length, due to the numerous shafts. It was stated that the New Croton Aqueduct was constructed in tunnel for the purpose of avoiding the purchase of expensive land along the Hudson River; also to place it in a less exposed position than the Old Croton Aqueduct, and render it less liable to be cut by hostile forces in times of insurrection and war. Probably the main reason was to avoid the repetition of the troubles with the Old Croton Aqueduct, whose history is replete with numerous breaks and interruption of service. This expectation has been realized, for the New Croton Aqueduct has furnished twenty years of uninterrupted service with little cost for maintenance.

Gradient of New Croton Aqueduct. The New Croton Aqueduct starts at elevation 140 at the Old Croton Dam and tunnels for a distance of 23.92 miles at a grade of 0.7 foot per mile, except at Gould's Swamp, under which the aqueduct was depressed for a distance of 1135 feet. From Van Cortlandt Park to the terminal gate house at 135th Street, a distance of 6.83 miles, the aqueduct is depressed below hydraulic grade, crossing under the Harlem River at an elevation of 300 feet below mean high water. At 135th Street the water rises vertically to near the surface and thence through eight 48-inch cast-iron pipes to Central Park Reservoir, a distance of 2.35 miles, making a total length of Aqueduct from Croton Lake to Central Park of 33.1 miles. The elevation of water surface at Central Park is 119 feet and the total fall in the aqueduct is 33.7 feet, an average of very nearly a foot to a mile.

Construction of New Croton Aqueduct. The aqueduct was constructed from thirty main shafts, and ten additional shafts added for construction purposes, and two inclines from the surface. The shafts were spaced 4000 to 7500 feet apart, although at difficult points they were only 400 to 1200 feet apart. The average distance between working points was 3400 feet. The depth of the shafts varied from 21 to 391 feet, the average being 127 feet. The shafts were timbered with 12″×12″ sets, 3 to 6 feet apart; back of these bents 3-inch lagging was placed, packed with cord wood or loose rock. Nearly all the shafts were lined with masonry, and are used for inspection, repair or ventilation. Two shafts adjacent to the Gould Swamp Siphon and the Harlem River Siphon are arranged to allow the pumping out of the low stretches. The depth of the tunnel varies from 50 to 500 feet.

To explore the line of the tunnel a considerable number of diamond-drill borings were made, although this was rather unusual for the time. Not enough borings were taken to fully develop the rock profile, with the result that the tunnel at several points ran out of rock into difficult soft ground. This was particularly so at Gould's Swamp, where, after a vain attempt to put the tunnel through at grade, it was depressed for a distance of 1135 feet, and built circular, 14 feet 3 inches in diameter.

Harlem Siphon. It was known that at the contact between the limestone and schist, a soft band of rock existed, and this was partly explored by diamond-drill holes from the surface of the Harlem River. An attempt was made to drive the headings through at an elevation −150, but Heading 25 North ran into a soft wet rock at the contact. This was bulkheaded off and the seam explored by horizontal diamond-drill holes. It was then decided to drop the tunnel to elevation −300, where no difficulty was experienced, the rock being reported to be even too dry, so that water had to be carried to wet the drill holes. The Harlem River Siphon was considered to be the boldest undertaking in the new Croton Aqueduct, carrying as it does water at a level of 420 feet below hydraulic grade.

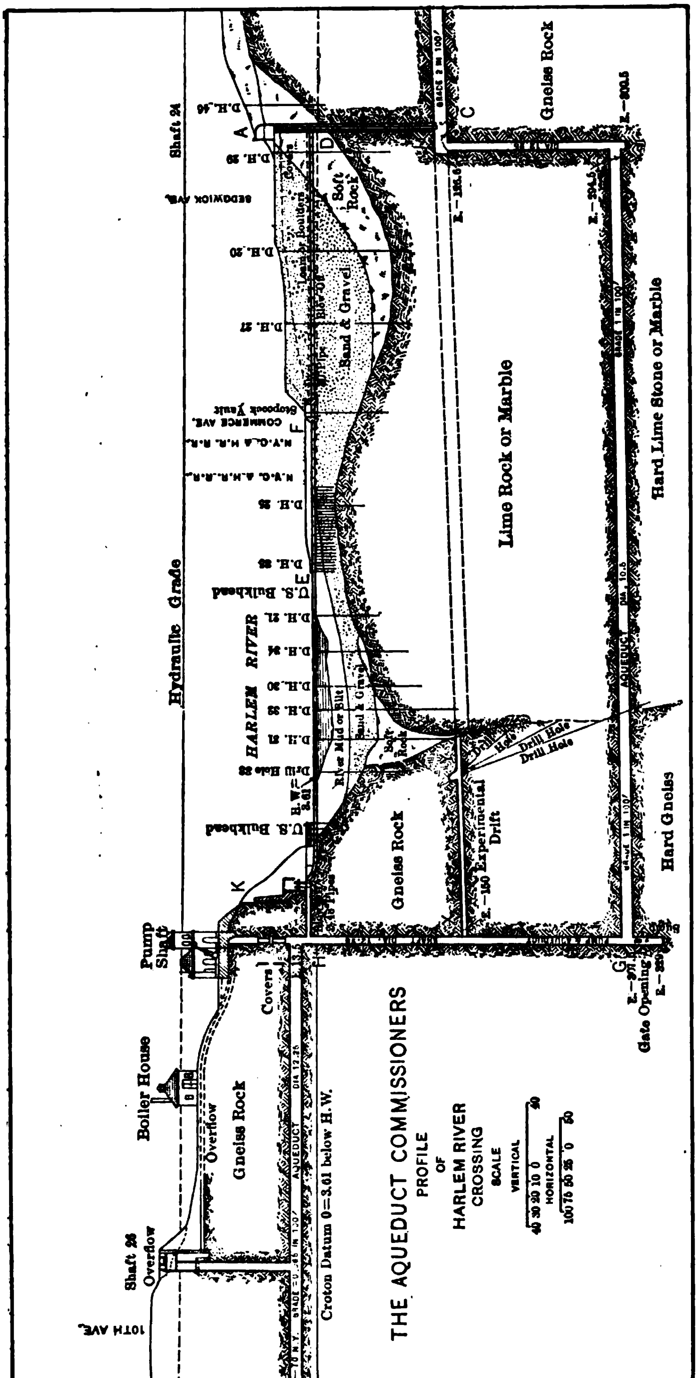


PLATE 2.—Profile of Harlem River Siphon for New Croton Aqueduct. The first deep-pressure tunnel. Completed in 1890. Later determinations are that the "Lime Rock" under the Harlem is the Inwood Limestone, the rock to the right the Fordham Gneiss, to the left Manhattan Schist.

It is but part, however, of a siphon 6.8 miles long, carrying water from the city border to well within Manhattan Island. As far as known, nothing like this had been attempted previously, unless we go back to ancient times, when it is said that the Greeks distributed water in a similar fashion. It is probable, however, that their tunnels were shallow and under slight head. The Harlem River Siphon has justified itself, as it has been in continuous operation for twenty years. The leakage from the whole 6.8 miles under pressure is said to be only a few hundred thousand gallons per day.

Construction of Tunnels for New Croton Aqueduct. The Croton Aqueduct was constructed by methods very similar to those now in use. The shaft contained two compartments in which cages were raised and lowered by large steam hoists, the excavation being removed in cars of about 1 cubic yard capacity. Large Rand and Norwalk compressors were installed at the tops of the shafts to furnish air at 80 to 100 pounds pressure. Ingersoll, Rand, Sergeant and Rattler drills were in use. The cages and hoists were Otis and Lidgerwood types. In the shaft sinking Cameron and Dean pumps were used. The headings were drilled from columns, two columns ordinarily being used, mounting either one or two drills, much as in present practice. It ordinarily took from six to nine hours to drill a heading of twenty holes, holes being used as follows in each heading: eight cut holes 8 feet deep, six side holes 7½ feet deep, eight rim holes 5½ feet deep. This heading broke about 100 square feet. The powders used were mainly dynamites, Atlas and Forsyth. In addition, "rackarock" powders were used to some extent. This was mixed on the ground from its constituents, chlorate of potash and nitrobenzole, portions 75 and 25 per cent. At one time this was considered good practice, as the harmless ingredients could be shipped separately, but it is now considered that there is more danger in preparing the powders on the ground than in shipping, and that it is better to have the mixing done under careful supervision at the powder mill.

It is interesting to note that incandescent electric lights were introduced into these tunnels in 1886, although at first arc lamps were used. Some attempt was made at artificial ventilation, a few Baker and Sturtevant blowers being installed to pump air through pipes into the headings, but the main reliance for ventilation was upon the air released by the drills. The top headings were driven about 100 feet in advance of the bench, much as is done now in the standard American practice, and the progress made was only a little less than is now usual in tunnels of this class, the average progress of headings being from 25 to 40 feet per week. A very creditable record was made in tunnel 16 N, where the contractors, Denton, Breuchand & Co., in order to see what they could do, worked their plant and men at maximum capacity, and succeeded in excavating 127 feet of heading in one week. It is interesting to note that the ordinary contract price for excavation of rock in tunnel on this Croton Aqueduct was somewhat less than that for similar rock on the Catskill Aqueduct, averaging about $5.50 per yard. This was probably due to the lower price of labor at the time, and a longer working day, there being no eight-hour law at that time. This is only partially overcome by the better progress made at the present time.

Consumption of Water at Opening of New Croton Aqueduct. When water from the New Croton Aqueduct was turned into the Central Park Reservoir in 1890 the chronic shortage of water which had existed for many years was immediately relieved and the consumption of water jumped from 102 million gallons per day to 170 million gallons. The city now (population 1,720,000) settled down with the comforting assurance that it would have an abundance of water for many years, the capacity of the new aqueduct being over 340 million gallons per day. It was, nevertheless, known to engineers that the Croton supply could not be sufficient very long, in view of the great growth in population and the increased per capita consumption.

The Croton Aqueduct was purposely built larger than the probable yield of the Croton watershed even when fully developed. For some years the increased consumption was provided for by the building of new reservoirs, particularly that formed by the construction of the new Croton dam. By 1899 the consumption had increased so rapidly that it bade fair to overtake the supply, yet little effort was made to prevent waste.

Ramapo Water Company. As the City of New York was making no effort to secure a supply outside of the Croton watershed, some shrewd up-state politicians joined with others in the city to form a water company known as the Ramapo Water Company, which secured very broad powers from the legislature; in fact, its powers of acquiring water rights exceeded that enjoyed by any municipality. By simply filing plans with any county clerk it could acquire both reservoir rights and routes for aqueducts; and any objecting property owner had to file a protest within fifteen days and guarantee to pay the expenses of a commission to be appointed by the courts in case of adverse report. On this commission was to be one civil engineer who had the deciding vote. The property owner, also, was required to propose an alternate route or scheme which, in the judgment of this engineer, would be more favorable to the company than the company's own project. This company put a few surveying parties in the field and filed plans covering all available water routes in the lower part of the State. And, naturally, with the law as above outlined, few protests were made. The general scheme adopted by the Ramapo Company's engineers bears a remarkable resemblance to the final Catskill project now being constructed by the City.

Proposed Ramapo Contract. Greater New York, or the present city, came into being January 1, 1898. By its charter the Board of Public Improvements had the power to enter into contracts for water supply. Suddenly, on August 9, 1899, the Water Commissioner presented to this board a proposed contract with the Ramapo Company. This contract provided that the company was to supply the city with 200 million gallons per day at $70 per million gallons, and was to be in force for forty years. Consequently, the city, by this single contract, would be committed to the expenditure of about $200,000,000. To insure the performance of this contract the company was to supply a bond of only $100,000. Water was to be supplied at the city limits at a pressure " due to a head at 300 feet above mean tide." This contract was prepared in secret and suddenly sprung on the Board of Public Improvements with the assurance that a majority would favor it. However, the Controller and one other Commissioner strenuously opposed this contract, but were voted down. A request that four weeks be given to consider the proposition was also voted down. Finally, two weeks were allowed. This was more than sufficient. On the following day a tremendous storm of indignation arose, and the Ramapo contract proved to be one of the greatest sensations in the history of the city, making and unmaking many politicians.

Independent investigations of this project were immediately started by the Controller and the Merchants' Association of New York. It was shown that the cost of water from the Croton supply was about one-half of the proposed Ramapo rate, and that for less than the sum contracted for an entirely new system could be constructed by the city and paid for in the same time, whereas under the Ramapo contract the city would again be helpless at the end of forty years. The reason the Water Commissioner gave for favoring this contract was that the private water companies had obtained the water rights and that the city could not find any other watersheds; also that the consumption had grown so fast that in five years the capacity of the Croton watershed would be reached. The Water Commissioner stated that it was unnecessary to investigate this Ramapo project, as he had personally visited the sites of the proposed Ramapo reservoirs and found them to be sufficient. At the end of the two weeks' time given, the Ramapo project was dead, and no one dared to bring it up seriously again. In addition, Gov. Roosevelt secured the repeal of the charter of the Ramapo Company. The people on the watersheds awakened to the fact that their rights had been taken away from them secretly and became as wrought up, over the situation, as the city.

Investigation by Merchants' Association and John R. Freeman. This proposed Ramapo contract was of the greatest benefit by causing the city to realize that it was greatly in need of a new water supply. Many independent investigations were started which directly led to the construction of the Catskill Waterworks. The Merchants' Association in its report of August, 1900, went very fully into the situation. In addition to this, John R. Freeman reported to the Controller in 1900. This book has become a classic on the subject of water supply and is a mine of information and a most thorough review of the water situation at the time. Mr. Freeman reported that the Croton watershed would in a few years be drawn on to its full capacity, and favored the Ten Mile and Housatonic Rivers as a new source of supply. He considered this supply as ideal in every way, as an excellent dam site was found for an immense storage reservoir which could yield 750 million gallons per day by gravity to a distributing reservoir 300 feet above sea level. He also estimated that the cost would not exceed $10 per million gallons. But, unfortunately, insuperable legal obstacles stood in the way of acquiring these water rights, as Ten Mile and Housatonic Rivers are in the State of Connecticut, and there is no way by which New York State can condemn water rights or property there. At this time the government had not yet published its geological survey maps of the Catskill region, so that in the limited time allowed Mr. Freeman, he could not get an adequate idea of the Catskill watersheds and formed a rather unfavorable opinion of their possibilities.

Commission on Additional Water Supply. As the administration identified with the Ramapo contract fell into disfavor, no progress was made towards securing a new supply until a new Mayor, Seth Low, came into office. Mayor Low appointed in 1903 Messrs. Burr, Herring and Freeman to constitute a Commission on

Additional Water Supply for the City of New York. It was created to make a thorough, complete and exhaustive examination and investigation into the following:

(*a*) The quickest and best methods of reducing the waste of water in the city, and conserving and increasing the efficiency of the present supply.

(*b*) The probable future consumption of water in each of the boroughs of the city.

(*c*) The future supply for the City of New York; and

(*d*) A temporary supply, if feasible.

Findings of Commission on Additional Water Supply. The commission was supplied with ample means for carrying out these investigations and organized a large engineering force of six departments, in which were 200 men. An immense amount of work was accomplished in a very short time, and a printed report was issued in 1904. The commission found that the waste of water had been exaggerated; that when account was taken of the transient population of Manhattan Island the consumption of water was but moderate compared with other American cities. It nevertheless recommended that all efforts be made to prevent water waste, as it estimated that in five years the safe capacity of the Croton watershed would be reached. It recommended that an aqueduct to supply 500 million gallons per day be built, and found that the most available watersheds were those in the Catskills, consisting of the Esopus, Rondout, Schoharie and Catskill Creeks, these to be supplemented by other watersheds east of the Hudson near the line of the proposed Catskill Aqueduct, that is, Jansenkill, Wappinger Creek, and Fishkill Creek. This report met with great favor, and was regarded by, those capable of judging, as a thorough exposition of the needs of the city and showing a way out of the difficulties of the water situation.

For an immediate supply the watersheds above the Croton, such as the Fishkill, were to be first developed and used as an auxiliary to the Croton supply. Later, the Esopus and Rondout supplies were recommended for development. For Brooklyn, the commission recommended immediate development of the ground water supplies of Long Island. They also recommended filtration of the Croton supply and planned a complete filtration works at Stormville for the Catskill water, although they reported that the Catskill water was of exceptional purity and quality. The commission discovered that by building a higher dam than that proposed by the Ramapo Company at Olive Bridge across Esopus

Creek, a very large reservoir with a flow line of 560 feet above datum could be created, damming both the Esopus and Beaverkill Creeks at one time, and that the Esopus watershed alone would yield 250 million gallons per day.

Nothing further was done by the Low Administration toward providing a new supply, although the work on the Croton watershed was pushed to completion, the immense Croton Dam being completed and new reservoirs started on branches. J. Waldo Smith at that time was chief engineer of the Aqueduct Commission having this work in charge.

Restrictive Legislation for Supplies East of Hudson. Meanwhile, the counties in which the proposed reservoirs east of the Hudson were to be located became alarmed, fearing that their water rights would be taken away from them by the City of New York, and succeeded in having passed by the legislature a law prohibiting New York from securing further rights east of the Hudson. The reason for this was that many scandals arose in condemnation of land in the acquiring of water rights in the Croton watershed, although the City of New York in the long run probably largely overpaid the property owners. In the adjustment of the claims there were long and exasperating delays which bore very unequally on the residents. These restrictive laws were passed in the face of strong opposition from the City of New York, and followed the precedent laid down when certain restrictions were placed on the streams of Suffolk County at the eastern end of Long Island.

McClellan Bill. Mayor McClellan on coming into office in 1904 evinced a strong interest in the movement to provide an additional water supply for the City of New York, and in January, 1905, a water bill was introduced in the legislature providing for the appointment of a board to have charge of the proposed construction. The commissioners were to be nominated by three civic bodies. Objection was raised to this as unconstitutional. In order to show his non-partisanship, the Mayor promised to appoint these men from lists to be furnished unofficially by the Chamber of Commerce, the Board of Fire Underwriters, and the Manufacturers Association, hoping that this precedent would be followed in the future. The bill became a law in June, 1905, and was considered to be a model law, securing the principles of non-partisanship, home rule and efficiency. The three commissioners appointed were J. Edward Simmons of the Chamber of Commerce, Charles N. Chadwick, of the Manufacturers' Association, and Charles A. Shaw, of the Board of Fire Underwriters.

The Board of Water Supply. The Board was organized in June, 1905, and by August 1st it had appointed John R. Freeman as consulting engineer, J. Waldo Smith as chief engineer, and a little later William H. Burr, and Frederick P. Stearns as consulting engineers. By October of that year, the Board of Water Supply had made a report to the Board of Estimate, submitting schemes with maps for obtaining water from Catskill sources. This met with no opposition and was adopted unanimously by the Board of Estimate.

State Water Supply Commission. A law was enacted at the same time as that creating the Board of Water Supply for the city, establishing a State Water Supply Commission which was to have general charge of the water resources of the State. This law made it necessary for a city, before proceeding to the construction of any water works, to secure the formal approval of the State Commission. Recently, the work of the State Water Supply Commission has been taken over by the Conservation Commission of the State of New York.

A small engineering force was put into the field by the Board of Water Supply for the city, which surveyed a new aqueduct line from the Ashokan Reservoir on Esopus Creek to New York. With the aid of the information gathered by them and the invaluable United States Geological maps of the State, a large, comprehensive map showing the proposed reservoir and routes of the aqueduct was prepared and submitted for approval to the State Water Supply Commission. This was barely three months after the appointment of the chief engineer. After extended hearings at Kingston, where a great deal of opposition to the project on the part of the residents of Ulster County developed, the State Commission gave favorable decision May 18, 1906, leaving the way open for construction. This gave the city authority to draw on Esopus, Rondout and Catskill Creeks, and other minor streams in the Catskills, but for some legal reasons permission to draw on Schoharie Creek was not given. It also carried with it general approval of the route of the aqueduct. This was quite different from that proposed by the Commission on Additional Water Supply, due to the fact that it was now unnecessary to go near reservoirs or streams east of the Hudson, as their use was barred by legislation.

Future Supply for City. The only projects which can seriously compete with the Catskill supply are those of the Housatonic, Central Hudson, and Upper Hudson or Adirondack supplies. The Corporation Counsel rendered an opinion that it was useless to

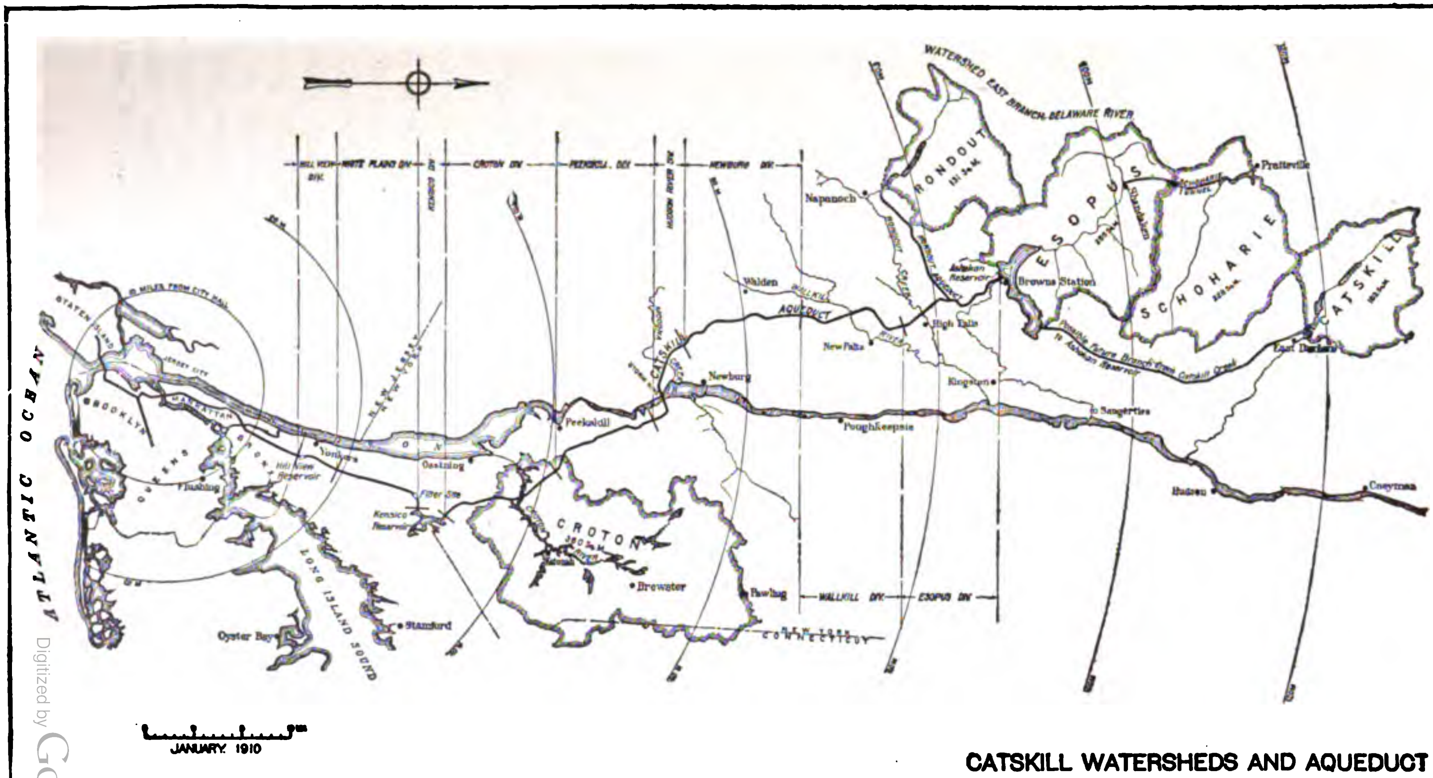


Plate 3.—Map of Catskill Mountain and Croton Watersheds. Approximate location of Catskill Aqueduct and Divisions.

attempt to secure water from the Housatonic, as the legal obstacles were almost insuperable. The Commission on Additional Water Supply found that the Central Hudson supply in the neighborhood of Poughkeepsie would have to be filtered and pumped. In addition, impounding reservoirs would have to be built in the Adirondacks, to prevent at times of extremely low flow, the salt water from advancing well up the Hudson. This would make the Hudson supply decidedly more costly and unsatisfactory than any gravity supply. The Adirondack supply was found to be excellent, but due to its great distance and high value of the water powers, its cost is almost prohibitive at the present time, although it is probable that the next supply, when New York will have outgrown the Catskill supply, will be obtained from the upper Hudson or Adirondacks.

Brooklyn Water Supply. The City of Brooklyn has always been able to obtain a sufficient supply of water from Long Island, and a portion of its own area has supplied considerable water. Long Island is a great plain sloping gently toward the ocean, the northerly portion of the island bordering Long Island Sound being a terminal moraine. The hills here are irregular deposits of glacial drift, ranging up to a few hundred feet in height and cut into deeply by numerous bays. Except for the glacial drift, the surface material is very porous, being underlaid by a depth of from 40 to 60 feet of yellow gravel and quartz sand. Below this there is a blue clay stratum, and below this alternating layers of gravel, sand and clay for 500 feet or more. The main reservoir of water is that above the layer of clay. The surface streams on Long Island are insignificant and are mainly near the south shore, where they are fed to a considerable extent by ground water. The ground water slopes gently from the center of the island to the South shore, where its elevation is about that of sea level. On the North shore it drops off sharply to the level of Long Island Sound.

Long Island Sound Water Supply. The ground-water level at the center of the island is about 80 feet above sea level and slopes to sea level on the north shore in about 5 miles and on the south shore in about 10 miles. The plain bordering the south shore is from 10 to 20 miles in width and almost parallel to ground water and comparatively few feet above it. Shallow wells at any point in this plain reach cool, fresh, and palatable water, inexhaustible for ordinary purposes. This has given rise to the belief that an unlimited quantity of water can be obtained from Long Island; that it is only a question of more wells and more pumps. A careful investigation by the Brooklyn Water Department, the Commission on Additional Water Supply, and the Board of Water Supply has clearly shown that there are definite limits to this supply; that the island can be treated as an ordinary watershed dependent upon rain, the porous strata absorbing the water and storing it up as a reservoir. Incidentally, as the water seeps downward at rates up to 3 feet per day it is filtered and cooled and preserved in perfect sanitary condition until drawn upon. It is estimated that from 15 to 19½ inches of rainfall are absorbed per year. The water naturally flows toward either shore at an observed rate of about 2 feet per day. It is estimated that this watershed if fully developed would yield about 800,000 gallons per day per square mile, under ordinary conditions.

Wells and Underground Streams. The peculiarity of a ground-water reservoir is that it has to be drawn upon from a great many points to furnish its full yield, as any single well tends to drain out an inverted cone-shaped volume of ground adjacent to it. As ground water is reached within a few feet of the surface adjacent to the south shore, the tendency has been to place batteries of wells here and in the valleys of streams tributary to the bays bordering the shore. It has been found that these wells have to be very carefully pumped lest the flow of the ground water be reversed and the salt water flow inward toward the well. This has spoiled some wells, rendering them brackish. A still worse effect is to spoil an entire district, so that to restore the original freshness of the water it is necessary to abandon the wells for a period of several years. Various absurd statements have been made that the ground water of Long Island is maintained by streams flowing underground from Connecticut and New Jersey, and attempts have been made to locate these streams. One man even entered into contract with the city of Brooklyn to supply water from an underground stream which he claimed to have located. A battery of wells was driven, and the water elevated by air lifts. For a short time a considerable quantity of water was supplied, but very shortly it was found to fail and become brackish, proving that he had merely drawn too heavily on ordinary ground water.

The Ridgewood System. At present Brooklyn relies entirely on the Ridgewood System reinforced by various local supplies provided by water companies and pumping stations within the city limits. At present the Ridgewood system supplies about 150 million gallons per day from an area of 159 square miles. This is probably the largest and best underground supply obtained by any city. An aqueduct has been built from Ridgewood parallel to and distant from the South shore of Long Island for a distance of about 20 miles. This aqueduct intercepts numerous streams, but is supplied mainly from wells and infiltration galleries. The water flows by gravity through this conduit to the Ridgewood pumping station, where it is pumped to the Ridgewood Reservoir, at which the main supply mains of Brooklyn originate. The westerly portion of this aqueduct was built in 1860, and the easterly portion, or New Conduit, about 1890.

Subsequent to 1906 a 72-inch steel pipe line was laid parallel to the original aqueduct, having a capacity of about 50 million gallons per day, and will be about 24 miles long, into which the water from various batteries of wells will be pumped under full distribution pressure, supplying the city directly without passing through the Ridgewood pumping station. This pipe line will relieve the brick conduits, which were overtaxed, and will provide sufficient conduit capacity to fully develop the Ridgewood system. This system will draw upon thirteen surface streams, two infiltration galleries and about twenty-five driven well stations. The wells are usually wrought-iron pipes 2 to 8 inches in diameter, washed down by ordinary methods. Water enters these wells through a screened section 5 to 14 feet in length at the bottom of the well. A 2-inch well when first driven delivers from 30 to 40 gallons per minute. This, however, demands too high a velocity of water in the adjoining sand, which, when it contains fine material, tends to rapidly clog the screens. For this reason it is necessary to pull and redrive wells.

California Stovepipe Well. A new type of well, known as the California stovepipe well, has been used by the Board of Water Supply to obtain information respecting the ground-water supplies of Long Island. It appears to have many advantages over the ordinary driven well. This well was developed originally near Los Angeles, where it has been very successfully used in deep gravels. It is commonly about 12 inches in diameter, and consists of a double shell of short steel tube, each tube about 2 feet long and made up with one longitudinal lap-riveted joint. The tube is rolled in two sizes, the larger one fitting snugly over the smaller, and so placed that the ends of the outer shells come over the ends of the tube of the inner shell. The transverse joints are not riveted, but are held by friction, the ends, however, butting together firmly. The bottom section is made of thick steel plate with a strong cutting edge, and the whole is forced down by powerful hydraulic jacks, working against a heavily loaded platform and pressing down on a specially strong movable top section of well pipe. While the jacks are pressing the pipes downward a sand bucket is freeing the pipe from loose material. Special boring tools are also used to penetrate boulders. After being driven to the full depth, the sides of the well are perforated with a special cutter at a depth where water-bearing sand exists. These wells have the great advantage that they can readily be cleaned out by a sand bucket and reperforated after being clogged, saving the great expense of pulling up ordinary wells to clean and replace their strainers. At first it was difficult to obtain casing from Eastern manufacturers, it being necessary to import it at considerable expense from California, but later on even better pipe was furnished by an Eastern manufacturer who succeeded in turning out an electrically welded casing, cheaper, stronger and in every way more satisfactory than the riveted casing. These wells were driven up to a depth of over 800 feet and from 12 to 24 inches in diameter. Wells of this type are now in use on Long Island, yielding a part of the Brooklyn water supply.

New Sources of Supply for Brooklyn. Both the Commission on Additional Water Supply and the Board of Water Supply recommended that Brooklyn be supplied in the future from Long Island. This meant that Suffolk County, occupying a greater portion of the eastern end of Long Island, be drawn upon. Unfortunately, various residents of Long Island, including many influential men and clubs owning large estates, were fearful lest the ground waters be depleted, and were particularly concerned about certain trout streams and ponds supplied by ground-water infiltration. The farmers were also alarmed lest the ground water be so drawn down that they could no longer raise certain crops. The legislature many years ago passed a law which in effect prohibits the City of Brooklyn from drawing water from practically all the streams of Suffolk County. It has been shown, however, that by judicious drawing of ground water the farmers are not injured. The same amount of water is found in the top soil regardless of the depth of ground water, though possibly in a few swampy places the water might be drawn below the surface. This, however, is likely to result in an improvement.

Suffolk County Development. The Board of Water Supply made a very thorough examination of Suffolk County, driving many experimental wells, locating aqueduct lines, etc. The plan as outlined was to construct a concrete aqueduct of the cut-and-cover type, parallel to the South shore. Batteries of wells were to be sunk within a strip of about 1000 feet wide. These wells were to be so carefully placed as to draw down the ground water at most a few feet, intercepting the ordinary shoreward flow. This would result in but little damage to any interests. The aqueduct would have the peculiarity of increasing in size as it approached Brooklyn. It was to be of horse-shoe shape, similar to Catskill Aqueduct, of maximum section, 15 feet wide by 13 feet 6 inches wide, and 164 feet in cross-section; of 250 million gallons capacity per day. Its ordinary grade was to be about 0.60 foot per mile. It was computed that this system would supply the probable future needs of Brooklyn for a long period and could furnish a new supply within a few years. The cost of this supply would be about the same as that of the Catskill supply, though development cost would be much cheaper, the pumping running the total cost up towards that of the gravity supply from the Catskills.

Catskill Water for Brooklyn. The Ridgewood system when fully developed is capable of supplying Brooklyn with sufficient water until the Catskill supply is obtained in 1915. The Catskill supply, being delivered at a head of about 250 feet in Brooklyn, will effect great economies there, doing away temporarily with the necessity for maintaining pumping stations, redriving wells, etc. It will also allow the recuperation of the ground water where it has been heavily drawn upon. It seems likely, however, that the Suffolk County supply will ultimately be made use of, as an immense area in the Borough of Queens is destined to be built upon. The investigations of the Long Island ground-water supply made by the Board of Water Supply has been published in detail in a special book issued by that board.

CHAPTER II

THE BOARD OF WATER SUPPLY

Commissioners. The Catskill water works, although hardly second to the Panama Canal, has been carried out with identically the same organization as planned at the start, and its personnel to the present time has changed but little. Of the three original commissioners appointed June 9, 1905, the first president, J. Edward Simmons resigned January, 1908, shortly before his death. His successor, John A. Bensel, remained until he became State Engineer in January, 1911. He in turn has been succeeded by Charles Strauss as president. Charles A. Shaw resigned in 1911 and was succeeded by John F. Galvin. Charles N. Chadwick has been commissioner since the start.

Administration Bureau. Reporting directly to the Commissioners is the Administration Bureau, consisting of Secretary and two Assistant Secretaries, Auditor, Chief Clerk, Examiner of Real Estate and Damages, Adjuster of Taxes and Assessments, and the Superintendent of Board of Water Supply Police. Exclusive of the police, there are, at the maximum, about 100 men in the Administration Bureau. The police, known as patrolmen on the aqueduct, number about 360 men (maximum).

Police Force. The maintenance of the police force, although saddling a considerable expense on the city ($337,000 in 1910) was deemed necessary by the legislature of the State of New York for the reason that considerable disorder existed during the construction of the Croton water works, the local constables proving incapable of coping with the new and shifting population following the work. The law provides that the city maintain a police force along the line of the aqueduct sufficient to insure the peace of the neighborhood and to protect the citizens from the workmen and others attracted by the construction. This has worked admirably for the peace of the communities along the line of the aqueduct, very little disorder, robberies or violence being reported. Many villages are probably considerably more secure now than when their sole reliance was upon local constables, even though the population has been largely augmented by workers on the aqueduct. About twenty precincts were established at convenient places along the aqueduct line and at the reservoirs. The patrolmen are uniformed and many of them mounted. They patrol the roads bordering the work, railroad stations, etc., but do not attempt to regulate the affairs of the country towns other than to secure the inhabitants from disturbances from aqueduct workers.

Chief Engineer and Staff. J. Waldo Smith has been Chief Engineer and head of the engineering bureau since the organization of the board. John R. Freeman, William H. Burr, Frederick Stearns and Alfred Noble are consulting engineers. For special work, to report on geology, filtration, etc., other experts are retained from time to time. Reporting to the Chief Engineer directly are the Deputy Chief Engineer and six Department Engineers. These constitute his staff. Merritt H. Smith is Deputy Chief Engineer; Thaddeus Merriman, Department Engineer, is attached to the office of the Chief Engineer. C. H. Harrison, deceased, was Deputy Chief Engineer from March, 1909, to March, 1910.

Headquarters Department. Alfred D. Flinn is in charge of this department, the office of which is located in the same building with the Chief Engineer. He has charge of preparation of all contracts, including contract working drawings, etc., about 175 men (1911) reporting to him. This force designs all structures, inspects and tests all materials.

The other four departments are in the field and have their offices convenient to the construction of which they have charge.

Reservoir Department. Carlton E. Davis, Department Engineer Reservoir Department, located at Brown's Station, had charge of all the work north of the Esopus Creek, including mainly the work on the Ashokan Reservoir. Reporting to him is a force of about 145 men. Under him are two Division Engineers, H. S. R. McCurdy, in charge of the construction at Ashokan Reservoir, and Fred K. Betts, in charge of the real estate surveys, construction of highways around reservoir and sewers in Kingston. J. S. Langthorn was until 1911 in charge of the executive work of this department and the supervision of Hurley dikes. Mr. Davis resigned in 1912 to become Chief of the Bureau of Water at Philadelphia, and was succeeded by Geo. G. Honness.

Northern Aqueduct Department. Robert Ridgway, Department Engineer Northern Aqueduct Department, resigned in January, 1912, to become Engineer of Subway Construction, Public Service Commission, First District, New York, when he was succeeded

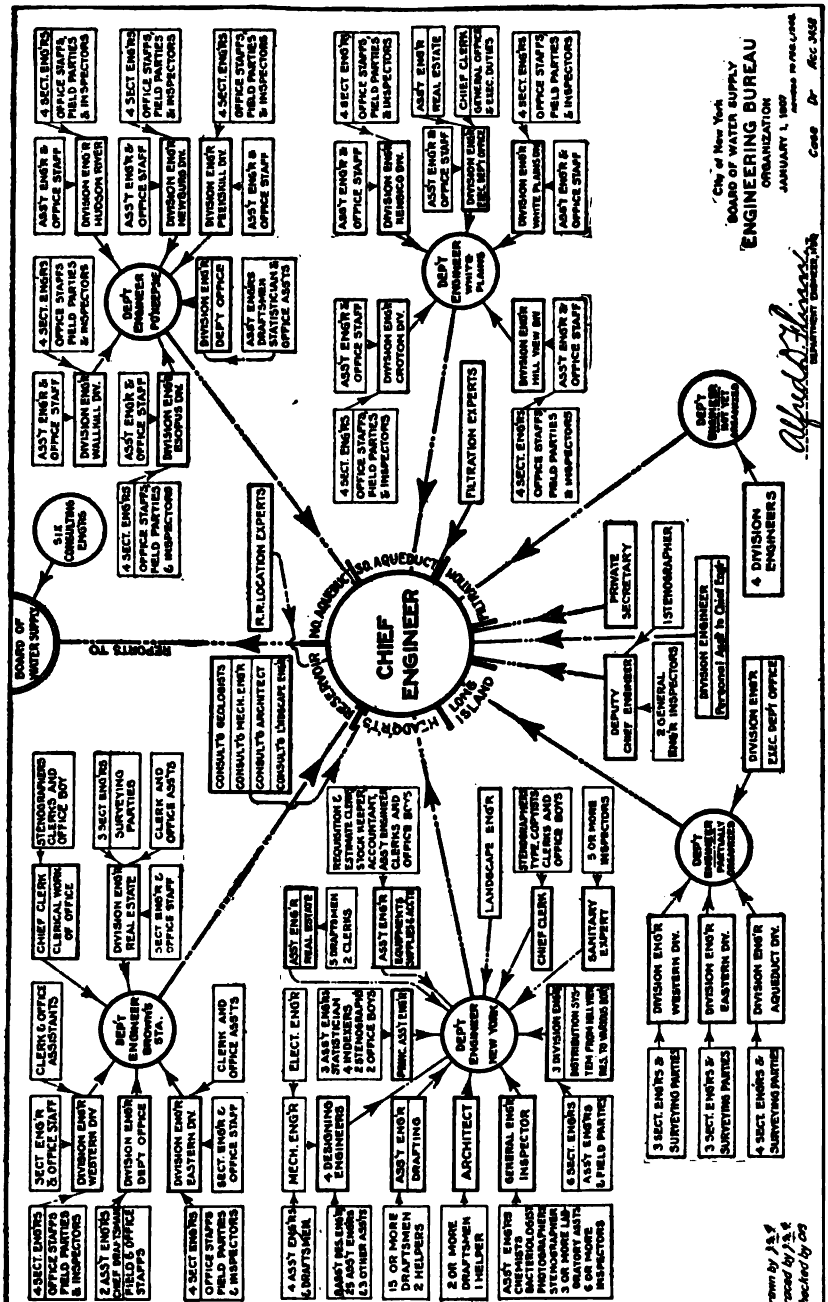


PLATE 4.—Diagrammatic Scheme of Engineering Organization Reporting to Chief Engineer, Board of Water Supply.

by R. N. Wheeler, with his office at Poughkeepsie. This department includes the Catskill Aqueduct between Esopus Creek and Croton Lake, a stretch of about 62 miles. It is divided into five divisions, as follows: Esopus Division, office at High Falls, Ulster Co., Division Engineer, Lazarus White to 1911, later John P. Hogan. Walkill Division, office, New Paltz; Division Engineer, L. C. Brink, succeeded 1911 by James F. Sanborn. Newburgh Division, office, Walden, N. Y.; Alexander Thomson, Jr. Hudson River Division, office, Cornwall-on-Hudson; Division Engineer, William E. Swift; succeeded by Frank E. Clapp as Acting Division Engineer. Peekskill Division, office, Peekskill; A. A. Sproul, Division Engineer, deceased, succeeded respectively by James F. Sanborn, Alexander Kastl and G. P. Wood. Each division is divided into four or five sections under a section engineer having charge of a contract or portion of large contract, usually consisting of about three miles of aqueduct work. Each section engineer has an office directly on the work and has an assistant and one or two field parties reporting to him on cut-and-cover work. On siphon tunnels with several shafts a section engineer usually had charge of three shafts.

Field Offices. A plan was followed which added very much to the comfort of the men and to their efficiency, the field engineers being provided with convenient and comfortable offices. In most cases new buildings were built designed carefully by the architect of Headquarters Department in consultation with the field engineers. On cut-and-cover work section offices provided with plumbing, heating system and fireproof vault were provided. On siphon or pressure tunnel a small office known as a locker house was built at each shaft under the main contract. These were provided with heat, light and shower baths, also in some cases with telephone service. The cost of these houses were amply returned to the city in the increased efficiency of the engineering force. With the facilities provided a force smaller, than would have been otherwise necessary, could do the work. The provision for telephone work is a particularly valuable one, although not provided in all cases. Even in New York it was found advisable to provide for the engineers locker houses equipped with hot- and cold-water supply, shower baths, heat, etc.

Southern Aqueduct Department. Frank W. Winsor, Department Engineer, has his office at White Plains and has charge of all work south of Contract 2 and north of the city line. Reporting to him were Geo. G. Honness, in charge of the Croton Division, succeeded by C. M. Clark, office, Pleasantville, also Wilson Fitch Smith, office, Valhalla, in charge of the Kensico Division; E. W.

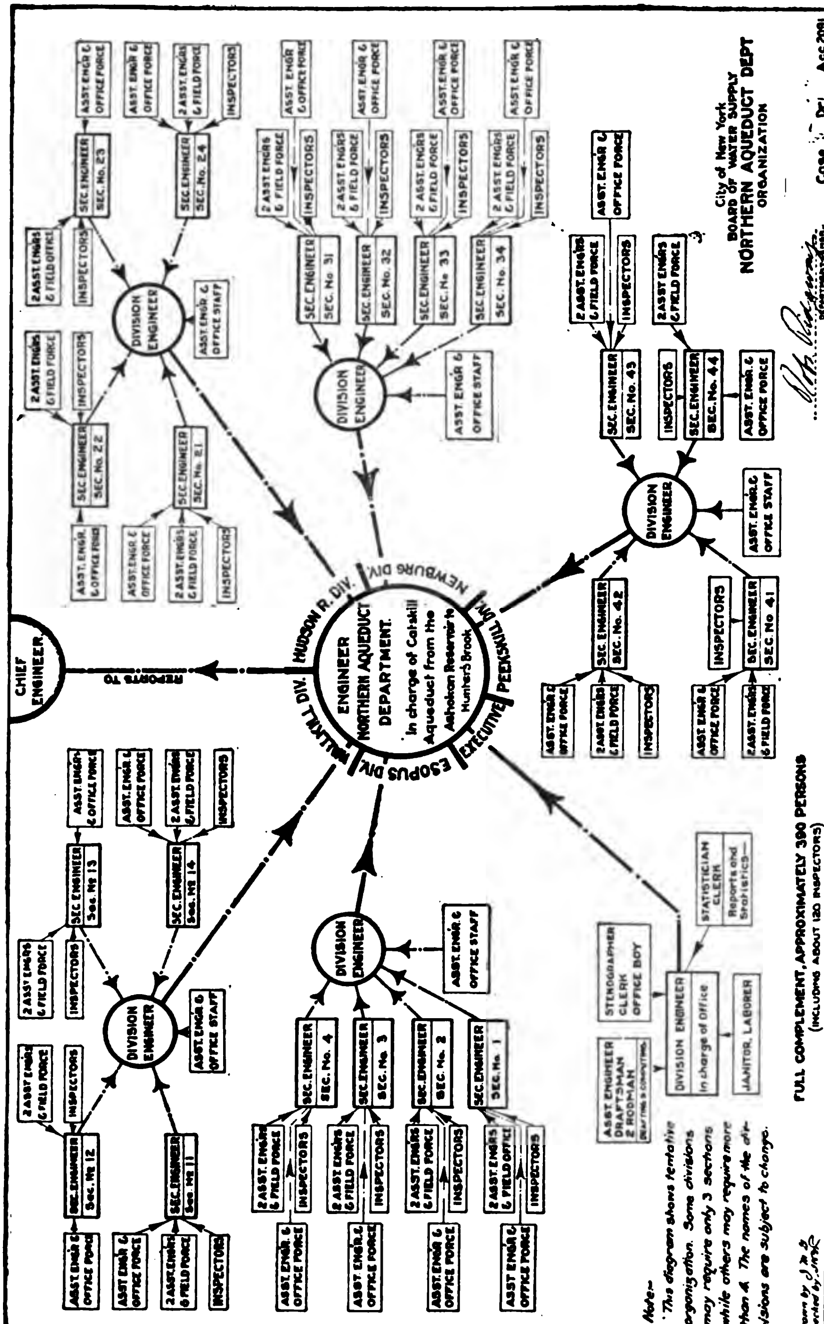


PLATE 5.—Diagrammatic Scheme of Engineering Organization of the Northern Aqueduct Department.

Clarke, office, Elmsford; White Plains Division, Charles E. Wells, Division Engineer, Yonkers, Hill View Division. Each of these divisions is subdivided into sections, with field office, as in the Northern Aqueduct Department.

City Aqueduct Department. The City Aqueduct Department, under Walter E. Spear, organized in 1911, has charge of all work in New York City, and is divided into three divisions, viz., Bronx Division, B. H. Wait, Division Engineer, all work at shafts 1 to 12 of City Aqueduct; Manhattan Division, all work at shafts 13 to 24, L. White, Division Engineer; Conduit and Reservoir Division, J. S. Langthorn, all conduits in Brooklyn, Queens, and Richmond Boroughs, and Silver Lake Reservoir, Staten Island.

Forces of the Board of Water Supply. The following is a summary of the force of the Board of Water Supply as it existed late in 1912.

COMMISSIONERS.

Charles Strauss, President.
Charles N. Chadwick.
John F. Galvin.

ADMINISTRATION BUREAU.

Joseph P. Morrissey, Secretary.
Henry C. Buncke, Auditor.
J. M. S. Millette, Chief Clerk.
George F. Shrady, Superintendent, Board of Water Supply Police.

ENGINEERING BUREAU.

J. Waldo Smith, Chief Engineer.
Merritt H. Smith, Deputy Chief Eng.
John R. Freeman, Consulting Engineer.
William H. Burr, Consulting Engineer.
Alfred Noble, Consulting Engineer.
Frederic P. Stearns, Consulting Eng.
Alfred D. Flinn, Department Engineer.
George G. Honness, Department Eng.
Ralph M. Wheeler, Department Eng.
Frank E. Winsor, Department Engineer.
Walter E. Spear, Department Engineer.
Thaddeus Merriman, Dept. Engineer.

Summary of Board of Water Supply Forces.

Commissioners		3
Administration Bureau:		
Secretary and clerical	66	
Patrolmen on aqueduct	326	392
Engineering Bureau:		
Chief Engineer and staff	13	
Headquarters Department	154	
Reservoir Department	152	
Northern Aqueduct Department	198	
Southern Aqueduct Department	269	
City Aqueduct Department	193	979
Totals	...	1374

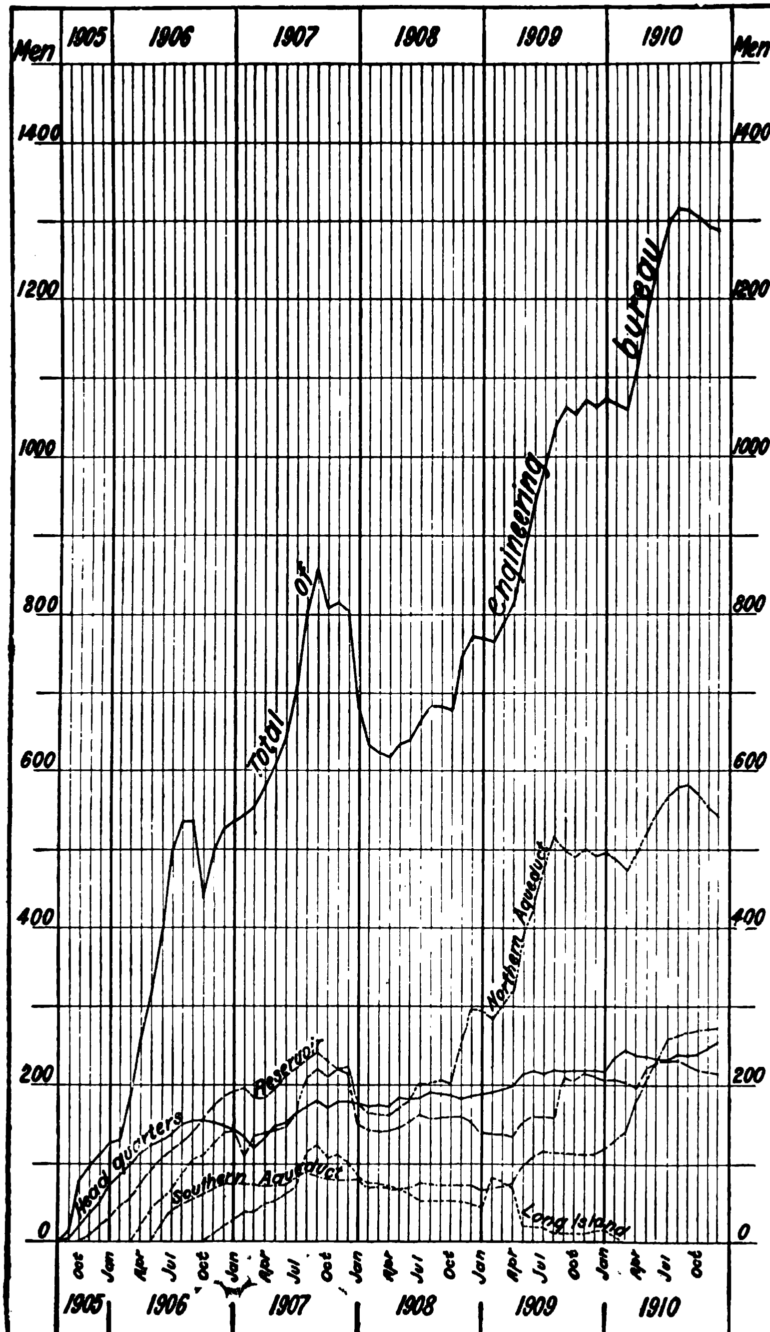


Plate 6.—Diagram Showing Fluctuations in Engineering Bureau Forces, 1905–1910.

The fluctuation and extent of the contractors' forces are shown on Plate 6. Fluctuations in the engineering forces are shown on Plate 7.

Details of Engineering Organization. The Civil Service. To give a more precise idea of the scheme of the engineering organization the diagrams on Pls. 4 and 5 are reproduced, showing graphically the organization of the engineering bureau under the chief engineer and one of the departments in detail, the Northern Aqueduct Department.

With the exception of the Chief, Consulting Engineers, Department Engineers and a few of the Division Engineers, the entire force of over 1500 men was procured through the Municipal Civil Service of New York City by competitive examination, or by transfer from other city departments of men who had already passed competitive examinations for similar positions. The demand was so great, at the start of the work, that enough engineers resident of New York State could not be secured and the examinations were thrown open to men from other States. Thus many engineers formerly in the employ of the Metropolitan Water Board, Massachusetts (Boston Water Works) secured positions with the Board of Water Supply. Other men were connected with work in New York City or State, such as the Rapid Transit Subway or the New Croton Aqueduct, or were in the lower grades, recent graduates of various technical schools. A large percentage of the engineering force were graduates of technical schools such as Columbia, Harvard, Cornell, Massachusetts Institute of Technology, etc.

The Croton Aqueduct was built before competitive examinations for engineering positions in the Civil Service was well established. Those now with the Board of Water Supply will testify that an immense improvement has taken place in the personnel of the city's engineers since that time (about 1890). It speaks volumes for the civil service idea when we consider the high efficiency and character of the work done by the engineers of the board on a construction with already $87,000,000 of work completed to end of 1912.

Grades and Salaries of Engineering Force. The various engineering grades under Civil Service are as follows: axeman, $60 per month; rodman, $80 per month; transitman or leveler, $100 per month; inspector, $120 to $130 per month; assistant engineer, $1350 to $3000 per annum. Until recently, the assistant engineer could be progressively promoted to positions of higher responsibility from charge of line and grade party, to section engineer. This made for flexibility and gave the men the incentive to work hard in an expanding organization.

In addition to the regular engineering work of the board, the forces of the Board of Water Supply were called upon to do a great deal of direct work such as would be done ordinarily by contract. Many boring machines were bought and placed directly in charge of the engineering bureau, the necessary supplies being acquired by direct purchase. In addition, many test pits were dug to ascertain the nature of the materials along the line of the aqueduct. The largest direct construction was the sinking of the east and west shafts for the Hudson River Siphon after the first contractor had abandoned the work, with the shafts only 250 feet deep. The contractor's plant was taken over and new machinery bought and installed. With men obtained through the Civil Service Commission these shafts were sunk to a depth of over 1100 feet, and tunnels driven part way across the river at this level.

Acquisition for Land of Croton Water Works. It was realized at the beginning of the work that the acquisition of the necessary real estate would throw a heavy burden on the engineering force in the preparation of surveys, the tracing of deeds and boundaries, and other work necessary to assist the corporation counsel and commissioners of appraisal.

In the acquisition of the lands for the Croton Water Works the city had a much freer hand, it being only necessary to file maps showing the land required. Possession being obtained, the appraisal of damages was usually drawn out through a period of years, the property owner meanwhile being deprived of his land and being paid, in some cases, years after he was dispossessed. This caused a good deal of hardship, particularly for the small landowners and poor farmers, who did not know how to borrow upon the money due them from the city. Although the City in most cases paid overmuch for the land acquired together with deferred interest at 6 per cent, a great deal of ill feeling was created, so that the Catskill project met with a good deal of opposition for this reason.

The city compromised on a feature new to the law in New York State. The property owners were to be compensated to the extent of one-half the assessed valuation of the land at Jan. 1, 1905, before the city could take possession. In addition, the city was also to pay incidental damage to individuals or corporations suffering loss of business or loss of employment through the construction of the Catskill Water Works. This feature was new to New York State, but was employed to some extent in Massachusetts.

Real Estate Division, etc. As very large areas had to be acquired for the Ashokan Reservoir, a real estate division of the reservoir department was created and put in charge of Division Engineer F. K. Betts. A search was made of all the deeds covering this area and the farm boundaries run out. Accurate real estate maps showing the parcels to be acquired, acreage, etc., were prepared and lithographed, a set of about fifty parcels constituting a section. Application was made to Supreme Court of the county for the appointment of three commissioners of appraisal for each section, there being about forty-five sections in all. These applications and all subsequent legal work were in charge of the Corporation Counsel of the City of New York, who established headquarters at Kingston. After the commissioners were appointed hearings were held, evidence being furnished by the property holders and their counsel and by experts furnished by the Corporation Counsel, the engineers acting as advisers being called upon occasionally to testify as to bounds, and technical matters principally involving water-power rights.

Water Powers. Water powers, real and imaginary, were the subjects of much controversy. Insignificant streams, formerly used for operation of mills and in most cases long since abandoned, assumed great proportions on paper, and extended hearings were held at which experts for the property owners and the city testified at great length. In numerous cases the cost of these hearings to the city was far in excess of the final award.

Proposed Constitutional Amendment. Although the acquiring of private property, even for public purposes, should be carefully guarded, it seems that altogether too much deliberation, delay and expense is in vogue at the present time. At the last election a Constitutional Amendment was proposed, but not passed, empowering the Supreme Courts to appraise property to be condemned, with or without a commission; the idea being that if specially competent judges are detailed for this work they will soon become expert, and the proceedings conducted much more expeditiously than by the usually inexperienced commission of three. In addition, the judges, having a fixed salary, will not have the incentive for delay as per diem commissioners, nor are they likely to be affected to the same extent by local feeling.

Land Surveys. Along the line of the aqueduct it was necessary to condemn a strip, usually about 200 feet wide, with larger areas at the shaft sites, tunnel portals, etc. This meant that all the farms passed through had to be surveyed and the bounds traced and deeds hunted up, etc. In a large number of cases it was found that the deeds were not on file, the property being handed down from father to son, in some cases, from the original settlers. It was required to exactly show the metes and bounds of the strip condemned. In addition to this, for the information of the commissioners, maps were prepared showing the whole area of which a part was seized by the city. This meant that many doubtful cases had to be decided, such as overlapping, errors and inaccuracies of deeds. As some of these were very hard to adjust, it was supposed that some of the results as shown on the maps would be contested, but very few controversies arose. The bounds of thousands of farms and other plots have thus been definitely determined and will remain as fixed by the engineers for a long time to come. This real estate work, of great magnitude in itself, had to be accomplished in a very short time, as no contracts were allowed to be let until the title to the land necessary for construction had passed to the City of New York.

Direct Purchase of Land. A provision of the law by which the Board of Water Supply could acquire property by direct agreement with the owners proved of little help. The purpose of this provision was to save the expense of the long and costly litigation of the usual condemnation method. The city had authority to agree with the property owner as to the price to be paid for land needed for city purposes, but this agreement had to be approved by the Board of Estimate. In some instances where such agreements were effected, the payment was sometimes so long delayed that the property owner in the long run gained nothing by it, and obtained less than he probably would have received in condemnation proceedings. In addition, he was paid no interest on the amount agreed upon, nor were the expenses of the negotiations with the city paid him. In the regular condemnation proceedings the property owner's expenses for lawyers, expert witnesses, and traveling expenses are paid by the city, these being appraised by the commissioners. Also, he receives 6 per cent interest on the final award reckoned from the time the commissioners were sworn in. Were the Board of Water Supply empowered to pay the property owner immediately on agreement with him as to the value of his property, great savings in legal expenses could be made, and in many cases the property owner would accept less than the commission's awards if assured of immediate payment.

Cost of Real Estate. The total expense chargeable to real estate, including the year 1911, is about $12,000,000. Of this only

$250,000 is chargable to engineering expenses, which includes all necessary surveys, mapping, etc. Advertising alone amounted to $430,000. The fees and expenses of special counsel and commissioners of appraisal reached the total of $2,326,000. There was allowed as counsel fees and disbursements of parcel owners about $508,000. Interest on awards amounted to about $930,000. Of the $12,000,000 mentioned above, only $7;330,000 represents the direct award to property owners, the rest being expenses of one kind or another.

In 1911 over 2500 parcels were in the possession of the city for the work aggregating 21,135 acres.

Sanitary Work. Anyone who has had the responsibility of building camps for laborers and keeping them in satisfactory sanitary condition will realize that on a work of this magnitude many problems had to be dealt with and solved. A great majority of the contracts were carried out in the watersheds of streams supplying cities and towns. This was more particularly true of the Southern Aqueduct Department, a large portion of this work being located in the Croton watersheds and the streams supplying towns north of New York. In consequence of this, very strict sanitary provisions were introduced into the contracts. Most of these provisions were common to all the contracts, special ones being introduced where danger from contamination was the greatest.

It was provided that the camps were to be located on healthful, well-drained sites and to be provided with suitable and satisfactory buildings for the housing, feeding and sanitary necessities of the men, and suitable stabling for the animals employed upon the work. Plans of the layout of the camps and the construction of the individual houses were submitted for approval to the engineers. A good camp is shown on Pl. 8. The camps were required to be supplied with water for drinking and bathing purposes, and with sanitary conveniences for the men. During the first stage of the work the engineers alone enforced the sanitary provisions. Later on the services of sanitary experts were obtained. A regular contract was at first entered into with Dr. E. J. Lederle, who agreed to provide the following services: Supervise all sanitary matters in connection with the work of the board, prepare all plans and specifications in relation to such matters to accompany or be embodied in the contracts to be prepared by the Board of Water Supply; inspect and supervise the work in the field and to report as required to the Chief Engineer. He also was to make all necessary bacteriological and chemical analyses of water, etc., using

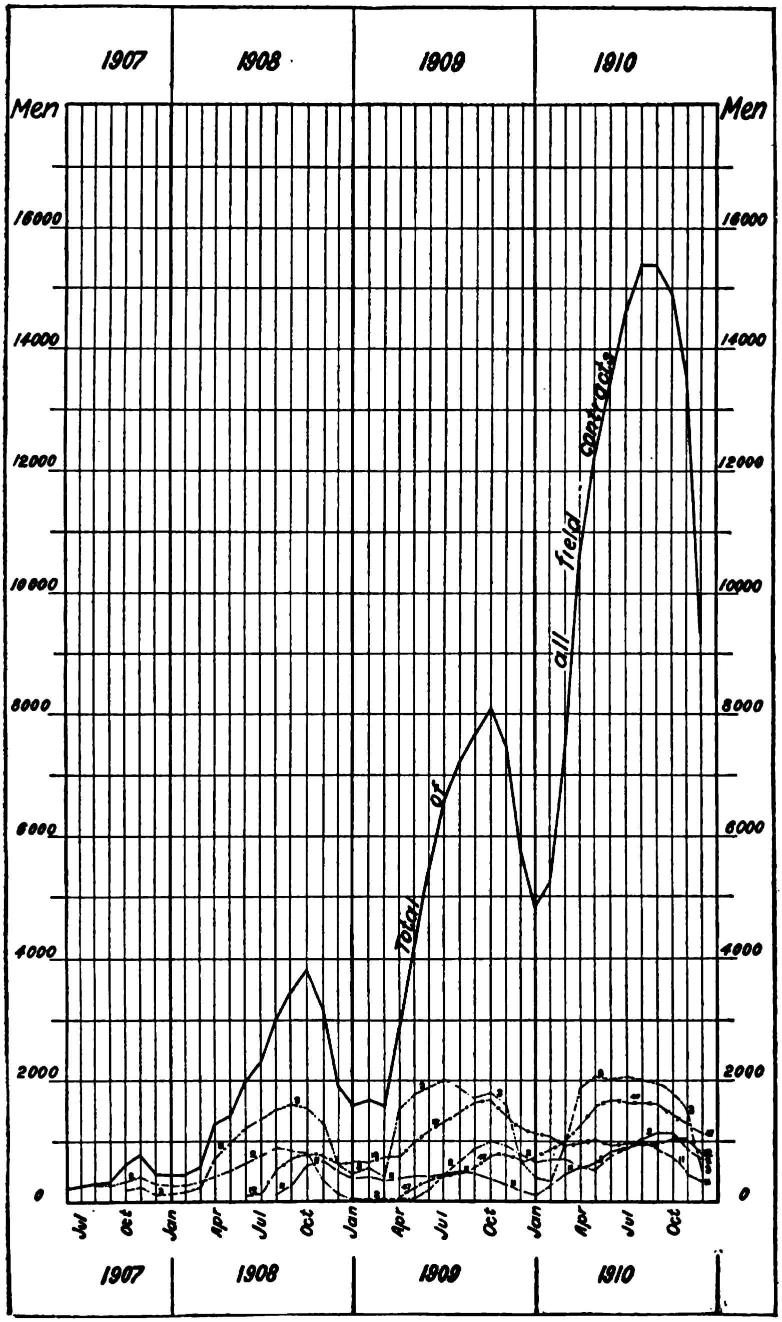


PLATE 7.—Fluctuations in Contractors' Forces During Years 1907–1910.

for this purpose, the facilities of the Lederle laboratory. Upon Dr. Lederle becoming Commissioner of Health for New York City in 1910, this work was taken over by Dr. Pease and A. J. Provost, Jr. They employed as their field representative Dr. David S. Flynn, who regularly visited the line of the work, consulting with the field engineers. The employment of sanitary experts did not in any way relieve the engineers of their responsibility for the sanitary conditions of the labor camps, the sanitary experts acting in advisory capacity. Each large contract provided that a medical officer was to be regularly in attendance at the camps where hospital facilities were to be provided. These company physicians made regular reports on forms prescribed by the sanitary experts. Very careful attention was paid to any contagious diseases, which were immediately reported to the sanitary experts by the engineers, and arrangements were made with the local health authorities to isolate and treat the patients. The remarkable sanitary conditions of the camp are shown by the fact that, despite their great number and an average population of about 15,000 in 1910, but 321 cases of communicable diseases and 86 deaths were recorded. Of these cases but 6 were typhoid, one a doubtful case of smallpox, 6 scarlet fever, 21 measles, 13 tuberculosis, 5 diphtheria, and 250 malaria. All employees of contractors were vaccinated before beginning work, unless they could show a recent certificate from a company physician on another contract, this requirement being very strictly enforced. The cases of typhoid fever were remarkably few, each case as developed being very carefully followed, the patient isolated and any suspected cause removed. At first there was opposition from contractors who were used to the loose conditions ordinarily obtaining in country labor camps; later on, although there was some grumbling over the enforcement of certain regulations, the contractors began to feel that the expense of laying out, building and maintaining the camps in sanitary condition was small and the benefits very large in proportion to the cost. They were thus relieved from the ever-present fear of epidemics which in the past had frequently demoralized work of this character. The better sanitary conditions and the cleanliness and healthfulness of the camps also made it easier to keep the men. Despite the fact that the work of the Catskill aqueduct was done during a period of rather low industrial activity, the contractors often found it difficult to keep up the full force required for the work, particularly on tunnel contracts.

Where camps were located in watersheds used for towns, it

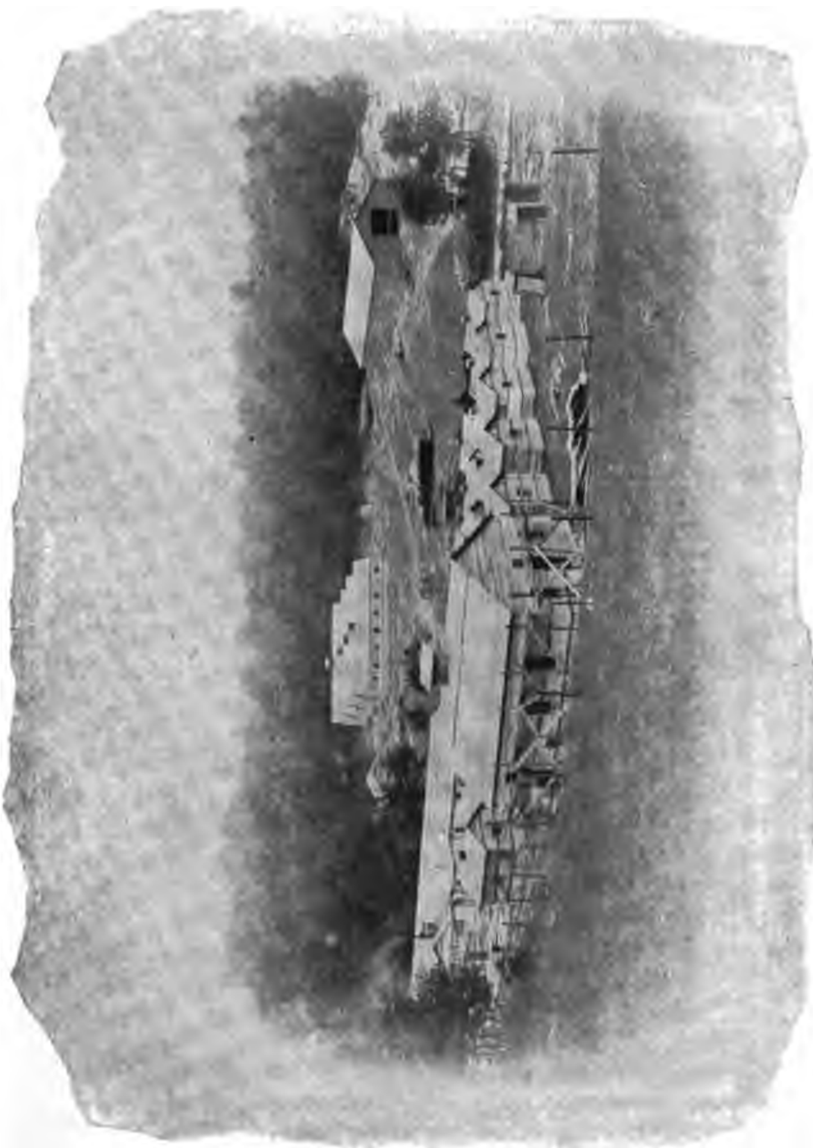


PLATE 8.—Typical Contractors' Camp on Catskill Aqueduct.

was required that their drainage be filtered. In most cases sand filters were used, besides sterilization by chemical dosing. It was even required to filter or sterilize water issuing from tunnels. I most cases all organic matter originating in camps was consumed in incinerators. The incinerators were either purchased from regular manufacturers, or constructed on approved lines of brick or concrete. It is probable that the destruction of organic matter by this method is the most sanitary and removes most potent causes of contamination from the camps. Moreover, it is comparatively inexpensive.

Sanitary Provisions of Contracts. Some of the sanitary provisions in force on watersheds are:

" The contractor shall take satisfactory precautions to prevent the contamination of or interference with any public or private water supply by his work or by his employees, and shall provide acceptable substitute supplies in case of unavoidable interference. The contractor shall furnish and erect, when, where and as directed, manproof fences along and adjacent to streams, reservoirs, etc., used as sources of potable water supply.

" All houses occupied by employees shall be thoroughly screened to exclude mosquitoes and flies. Quarters for the men shall be grouped in properly arranged camps. Camps shall, if ordered be enclosed by satisfactory manproof fences with not more than two entrances and the entire grounds illuminated by electric arc lamps or other acceptable lights. The contractor shall retain the services of acceptable, qualified, medical and surgical practitioners, to the number ordered, and shall have the care of his employees, shall inspect their dwellings, the stables and the sanitaries as often as required, and shall supply medical attendance and medicine to the employees whenever needed. They shall give their whole time to the work, there shall be at least always one on duty, etc. The contractor shall provide from approved plans one or more buildings properly fitted for the purpose of a hospital with facilities for heating and ventilating in cold weather and for screening and ventilating in warm weather. These hospitals shall have an ample number of beds to properly care for sick and injured employees, and shall be provided with all necessary medicines and medical appliances for the proper care of the sick and injured. Another building of approved design shall be provided and equipped as an isolation hospital, and any employee who shall be found to have a communicable disease shall be at once removed from the camp to this hospital and there isolated and treated as directed. Whenever practicable an employee having a communicable disease shall be removed when and as directed to an approved permanent hospital.

"Once a week, or more frequently, if required, the contractor shall give the engineer, in such detail as may be prescribed from time to time, a written report, signed by the physican in regular attendance, setting forth clearly the health condition of the camp or camps and of the employees. If any case of communicable disease be discovered, or any case of doubtful diagnosis, it shall be reported at once to the engineer, by telephone or messenger and confirmed in writing."

The filtering of drainage water from a camp on Sprain Brook watershed used for Yonkers was specified as follows:

"Slow sand filters of such size as permit a run off from the camp area of two-tenths of an inch per hour to be filtered in addition to other waste at a rate not exceeding two and one-half millions gallons daily per acre of filter surface, and said chemical treatment shall be done after filtering, using chlorinated lime having an the average not less than 30 per cent available chlorine, in approved amounts which will average about 25 pounds per million gallons of filter drainage. Said plants shall include storage basins of suitable size to hold a storm run-off of 3 inches on the whole camp area, and retention basins to facilitate chemical treatment, these basins to hold at least 15 minutes' flow from the filters at maximum rate."

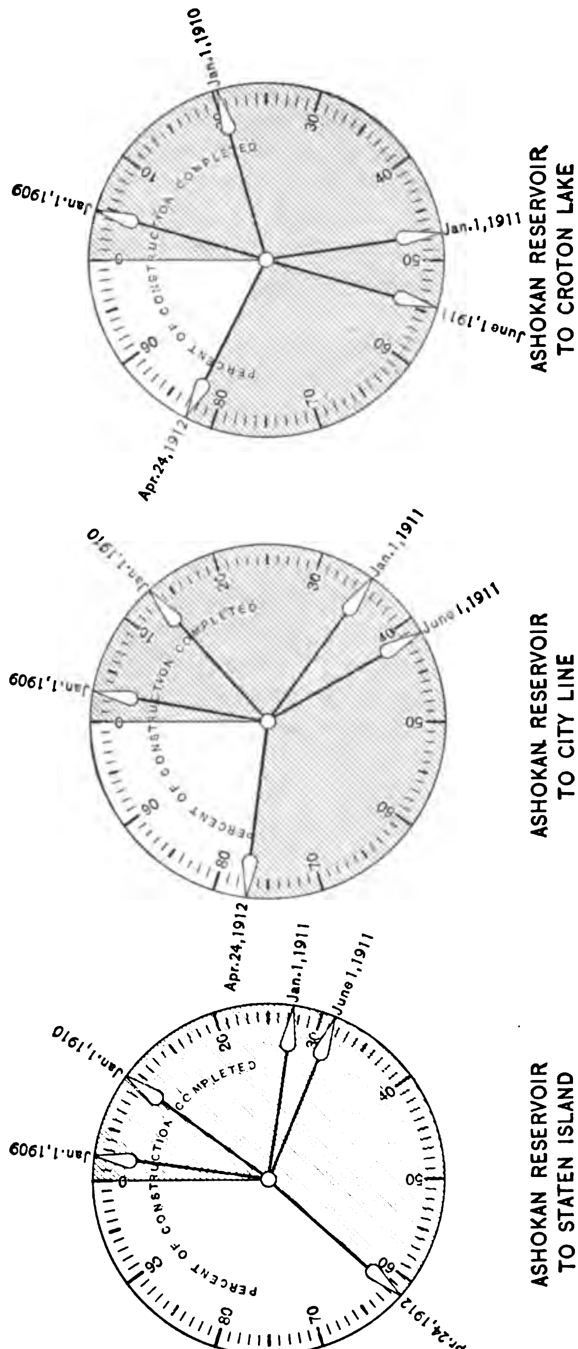


PLATE 9.—"Clock" Diagram Showing Progress on Construction Catskill Water System.

CHAPTER III

LOCATION OF CATSKILL AQUEDUCT

Proposed Catskill System of 1905. The first map, dated Oct. 9, 1905, approved by the State Water Supply Commission a few months later, showed an aqueduct location from the Catskills to and through New York City. Tributary to the aqueduct were to be the following watersheds yielding approximately as follows:

	Gallons Daily
1. Esopus watershed, area 255 square miles, with storage near outlet of about 70 billion gallons, about	250,000,000
2. Rondout watershed, area 131 square miles, with storage, in three reservoirs, of about 20 billion gallons, about	98,000,000
Three small watersheds tributary to Rondout, area 45 square miles, about	27,000,000
3. Schoharie watershed, area 228 square miles, with storage, partly in Ashokan reservoir, of about 45 billion gallons, about	136,000,000
4. Catskill watershed, area 163 square miles, with storage partly in Ashokan reservoir, of about 30 billion gallons, about	100,000,000
Six small watersheds, tributary to aqueduct, between Catskill Creek and Ashokan reservoir, combined area about 82 square miles, about	49,000,000
Total available yield of the Catskill sources, exclusive of (inter-state) Delaware tributaries	660,000,000

General Location of Aqueduct. The aqueduct location was based on former surveys of the Commission on Additional Water Supply, upon the U. S. Geological maps, and upon the results of early surveys of the first field party. It showed the aqueduct draining the Ashokan Reservoir at West Hurley and crossing the Hudson River a few miles below Poughkeepsie at New Hamburg, thence southward to Kensico Reservoir, which it was planned to enlarge to hold 40,000 million gallons, a supply sufficient for over eighty days in case of a break in the aqueduct above, ample time for inspection and repairs. The Kensico reservoir was also to be by-passed, and the aqueduct continued for 15 miles more to Hillview Reservoir, which was to have the function of equalizing the difference between the use of the water in the city, as it varies from

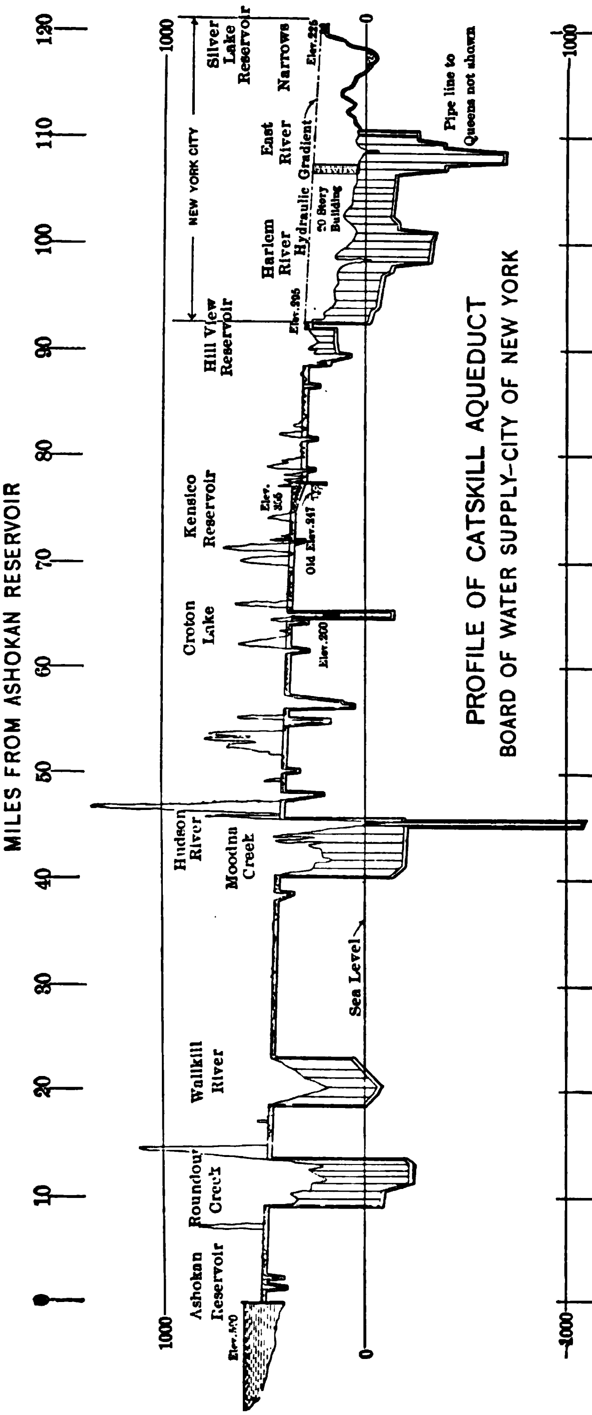


PLATE 1C.—Small Scale Profile of Catskill Aqueduct, Ashokan Reservoir to Silver Lake Reservoir.

hour to hour, and the steady flow of the aqueduct. This reservoir, with capacity of 900 million gallons, would also furnish considerable water in times of maximum draft, in case of conflagration, in addition to supplying a constant head to force water throughout the city. The first plan contemplated only the distribution of 120 million gallons daily, leaving the balance to be provided for by subsequent plans.

Due to a technicality, the Schoharie watershed was not granted. The State Water Supply Commission formally approved of all the other sources.

Changes in Location of Aqueduct Subsequent to 1905. As detailed investigations were made it was discovered that it would be much better to draw the water from near Olive Bridge Dam rather than from West Hurley, where the reservoir is shallow, requiring that the water be drawn from over the Beaverkill Swamps. In addition, the aqueduct running southward from the reservoir would be in a much more favorable country, shortening by several miles the aqueduct to a reservoir on Rondout Creek. A study of conditions in the field and on the geological maps revealed a much more economical location for the aqueduct west of the Hudson and a better crossing of the river further south than New Hamburg. A long stretch of cut-and-cover of economical construction, located in the Wallkill Valley, was secured as a substitute for an equivalent length of difficult work east and west of the Hudson at New Hamburg. In addition, a short crossing was secured at Storm King, instead of the original proposed crossing at New Hamburg, which would have been several miles longer, due to the wide and low-lying Fishkill plain bordering the Hudson at this point. The above changes were embodied on a supplementary map dated June 25, 1907, which was filed with the State Water Supply Commission. Approval of this was readily obtained.

The route of the aqueduct as finally adopted is shown on accompanying map, at end of book. The route of the City aqueduct is shown on Pl. 203, Chapter XIX.

Aqueduct within City Limits. As the work of construction progressed, it became apparent that the pressure or siphon tunnel type of aqueduct offered many advantages over surface lines, particularly in permanency of construction and economy of space, as little land is occupied and that only at shafts.

To employ steel pipe lines in the City to distribute the vast body of water carried by the aqueduct meant that a great many lines would have to be laid through the streets already congested with subways, underground structures and pipes of all sorts, and that the disturbance created by the laying of the pipes would have to be repeated at intervals to provide for renewals. It was proposed that a pressure tunnel be constructed southward from Hillview to well into Brooklyn, and that numerous shafts necessary for construction purposes be used as uptakes to distribute the water to the regular street systems of mains, to connect to which it would only be necessary to lay short lines. The tunnel would have the advantage that it could be readily constructed of large diameter, so that little loss of head would occur throughout its length, thus securing the full benefit of the high elevation of Hillview Reservoir, 295 feet, against the 116 feet of the Croton system. In case of conflagration, large quantities of water could be secured from pipe lines leading to the nearest shaft. As stated elsewhere, this scheme of pressure tunnels was partly used on the Croton Aqueduct system, water being delivered at the northern end of Manhattan Island through the Harlem River Siphon.

City Tunnel, Catskill Aqueduct. The proposed system of pressure tunnels in the city for the new water supply, however, was so novel and tremendous an undertaking that considerable opposition developed to its adoption. A commission of engineers, headed by Clemens Hershel, appointed by a committee of the Board of Estimate, after examination of the pressure tunnels under construction on other parts of the aqueduct, and after making comparative estimates of the cost of the two systems, reported heartily in favor of the deep rock tunnels through the city, confirming the statements of the engineers that the cost of the tunnels would be very much less than steel pipe lines; also that irrespective of costs, the tunnels would be better in every way. Formal approval of the City Aqueduct was given by the State Water Supply Commission in 1910. It is seldom that a proposition so original meets with such universal approval and is used on such an immense scale in the first instance.

Relative Cost of Croton and Catskill Water Works. The Catskill water system will cost about the same per million gallons daily capacity as the Croton system. This is remarkable considering that the Catskill Aqueduct is about three times as long, and reaches all five boroughs instead of only two, is delivered at a head of 295 feet instead of 160 feet, and is a much purer and softer water. The new Croton Aqueduct has a capacity of 300 million gallons per day with about the same cost per foot of length as the 500-million gallon Catskill Aqueduct. The surplus income of the Croton system, to date, has been carrying the interest charges on the bonds issued for the construction of the Catskill water system.

Various Types of Gravity Aqueducts.* The following types of aqueduct construction have been used for gravity aqueducts.

Aqueducts on Hydraulic Grade	Following natural surface	1. Open channel 2. Cut-and-cover
	Above natural surface	3. Embankment 4. Viaduct
	Below natural surface	5. Grade tunnel
Aqueduct below Hydraulic Grade	Following or above natural surface	6. Wooden pipe 7. Reinforced concrete pipe (pressure aqueduct) 8. Steel pipe
	Below natural surface	9. Pressure tunnel

Types Used on Catskill Aqueduct. The types are enumerated in the order of their relative cost, provided that in embankment or viaduct the elevation of invert above original surface is relatively small. On the Catskill Aqueduct, to avoid contamination, open channel is not used. Embankment is used as sparingly as possible, as it is deemed rather unsafe for an aqueduct of this size. Viaduct is not used to any extent, but in a few places the aqueduct was placed on arches and the whole covered by embankment. Wooden pipe is not to be considered for an aqueduct of this size. Reinforced concrete pipe is used to some extent under heads considerably less than 100 feet.

Comparison between Croton and Catskill Aqueducts. Except for the new Croton Aqueduct, the cut-and-cover type on hydraulic grade predominates. The new Croton Aqueduct was placed entirely in tunnel for the following reasons: greater permanency, decreased likelihood of accident, smaller cost of maintenance, smaller leakage, remote advantage of being less vulnerable in time of war, and decreased cost of real estate. The above advantages are very real, but unless there is some special condition which increases the importance of one or more of these, or some great saving could be made, they are outweighed by the smaller linear foot cost of cut-and-cover aqueduct. Comparing the New Croton and Catskill aqueducts, it will be found that the latter will have twice the capacity, although its cost is less than 10 per cent greater per linear foot. Making due allowance for the advantage in hydrau-

* Most of the material in the paragraphs to "Grade of Aqueduct" has been contributed by Division Engineer J. P. Hogan as the result of his extensive experience.

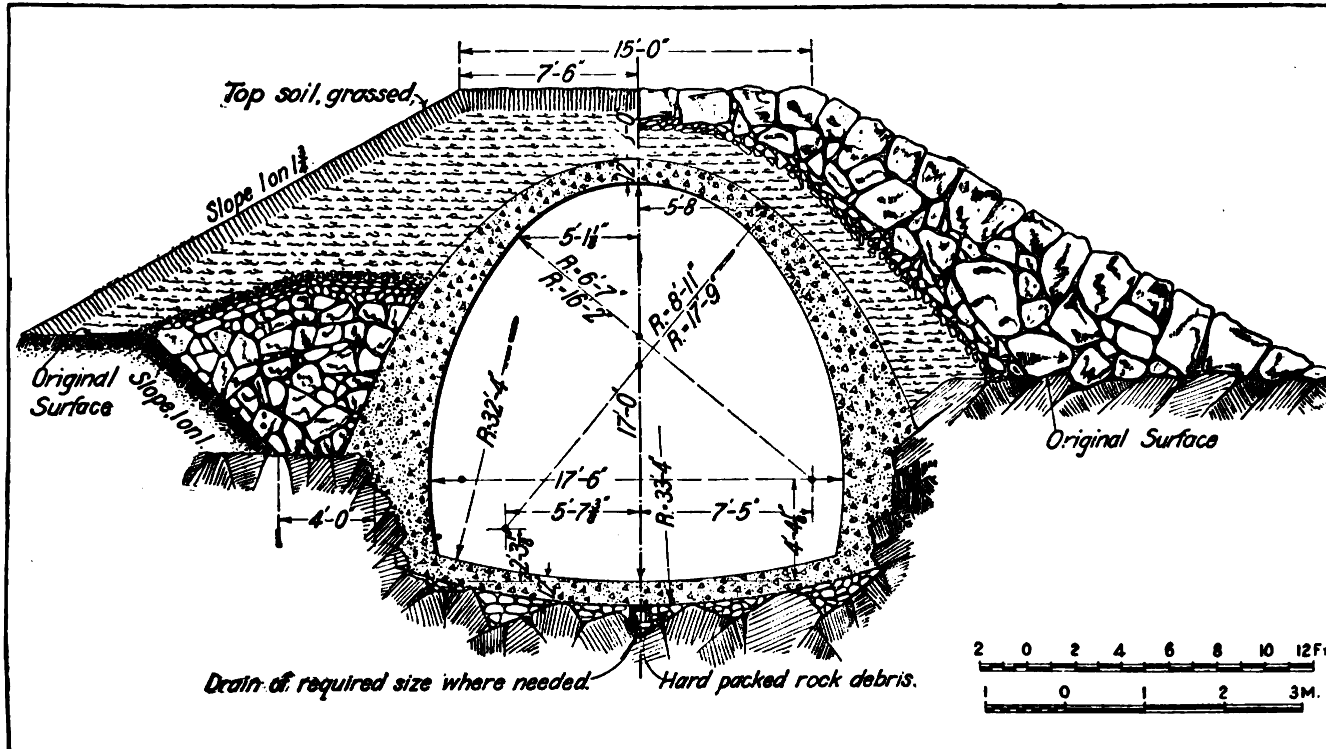
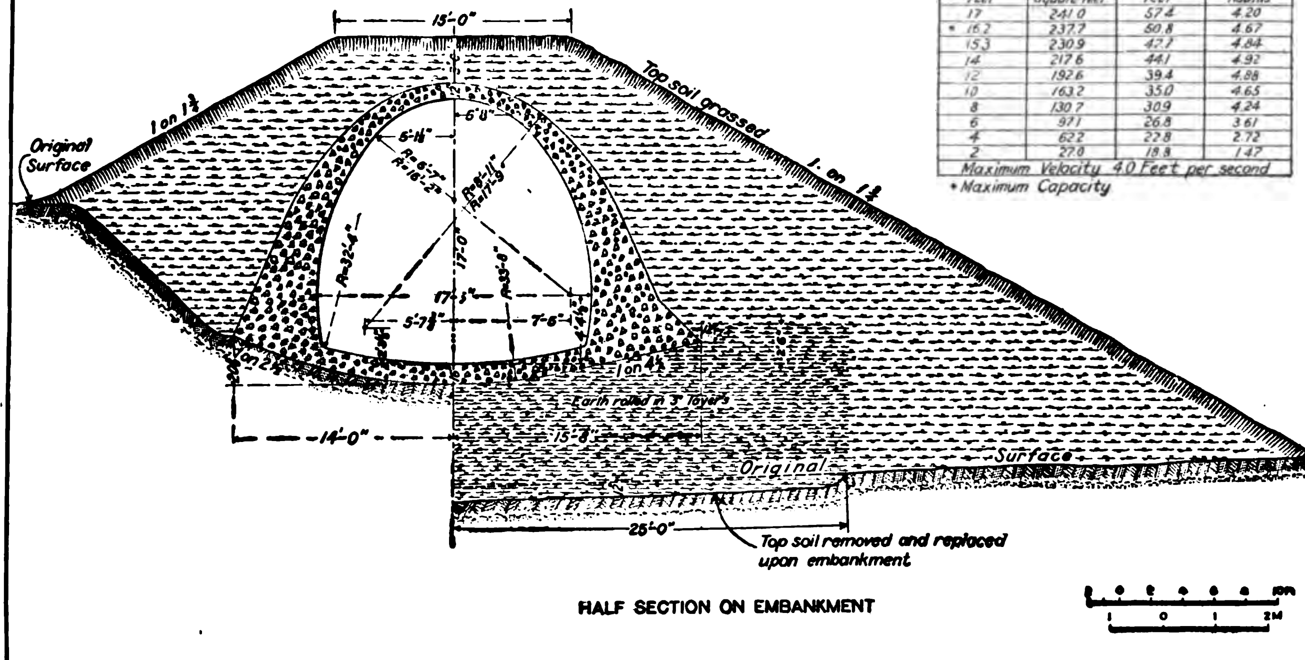


PLATE 11.—Cross-section of Cut-and-cover Aqueduct in Rock Trench, Showing Construction of Cover Embankment. Rock was usually excavated to a 6 on 1 slope. Minimum thickness of concrete along sides 20 ins., but usually thicker owing to disintegrated condition of surface rocks.



HYDRAULIC ELEMENTS
($S = .00021$)

Depth of Flow, Feet	Area, Square Feet	Wetted Perimeter, Feet	Hydraulic Radius
17	241.0	57.4	4.20
* 16.2	237.7	50.8	4.67
15.3	230.9	47.7	4.84
14	217.6	44.1	4.92
12	192.6	39.4	4.88
10	163.2	35.0	4.65
8	130.7	30.9	4.24
6	97.1	26.8	3.61
4	62.2	22.8	2.72
2	27.0	18.8	1.47
Maximum Velocity 4.0 Feet per second			

* Maximum Capacity

Plate 12.—Cross-section of Cut-and-cover Aqueduct in Loose Earth and on Foundation Embankment and Hydraulic Elements of Aqueduct. Side slopes usually 1 on 1. In firm earth 6 on 1, and 20 ins. minimum thickness of side concrete, above concrete slope of 3 on 1 used.

HYDRAULIC ELEMENTS

S = .00037

Depth of Flow Feet	Area Square Feet	Wetted Perimeter Feet	H[illegible]lic [illegible]
17.	198.6	52.2	3.60
• 16.25	195.6	46.0	4.25
15.3	188.5	42.7	4.41
14.	175.7	39.3	4.46
12.	152.4	35.0	4.35
10.	126.8	31.0	4.10
8.	100.2	26.9	3.72
6.	73.8	22.9	3.22
4.	47.6	18.9	2.51
2.	21.0	14.9	1.49
Maximum Velocity 4.8 Feet per second			

• Maximum Capacity

THEORETICAL QUANTITIES PER LINEAR FOOT

	Type A	Type B
Excavation, Cu. Yds.	10.2283	12.17
Concrete in Footings, Side Walls & Arch Cu. Yds.	2.3993	3.06
Concrete in Invert Cu. Yds.	0.1768	0.18
Timber for payment to Wall Plates, M Ft. B.M.		0.118
Timber for payment below Wall Plates, Est'd Average M Ft. B.M.		0.005
Tunnel Drainage, Lin. Ft.	1.00	1.00
Dry Packing, Cu. Yds.	0.2858	1.22

YPE A quantities based on arch 9 inches thick at crown.

TYPE B quantities based on 10"x10" timbers 5'0" c. to c., posts averaging 18" long.

Excavation, masonry, and packing quantities computed to ideal average line of excavation, i.e. B line.

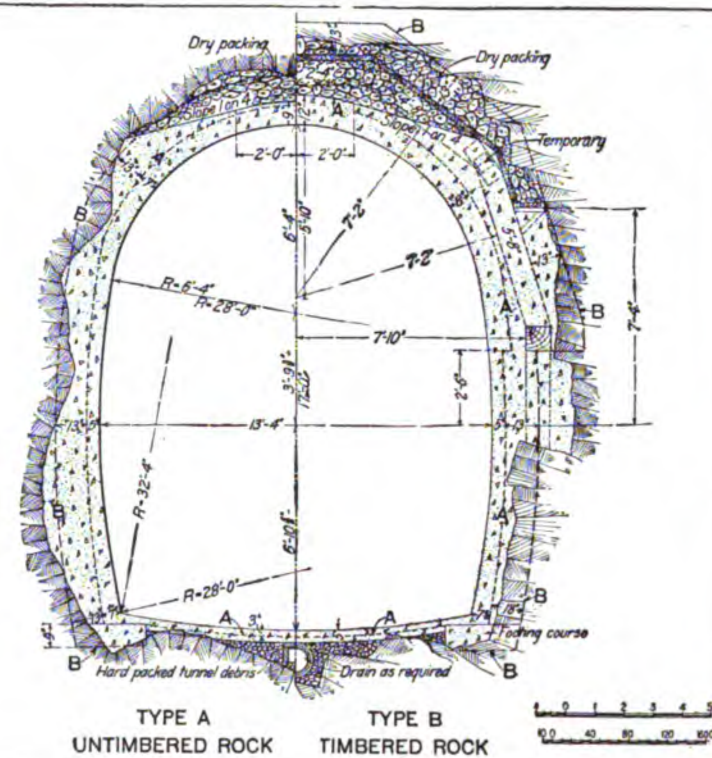


Plate 13.—Cross-section of Grade Tunnel in Untimbered and Timbered Rock. Also Table of Hydraulic Elements and Quantities per Linear Foot.

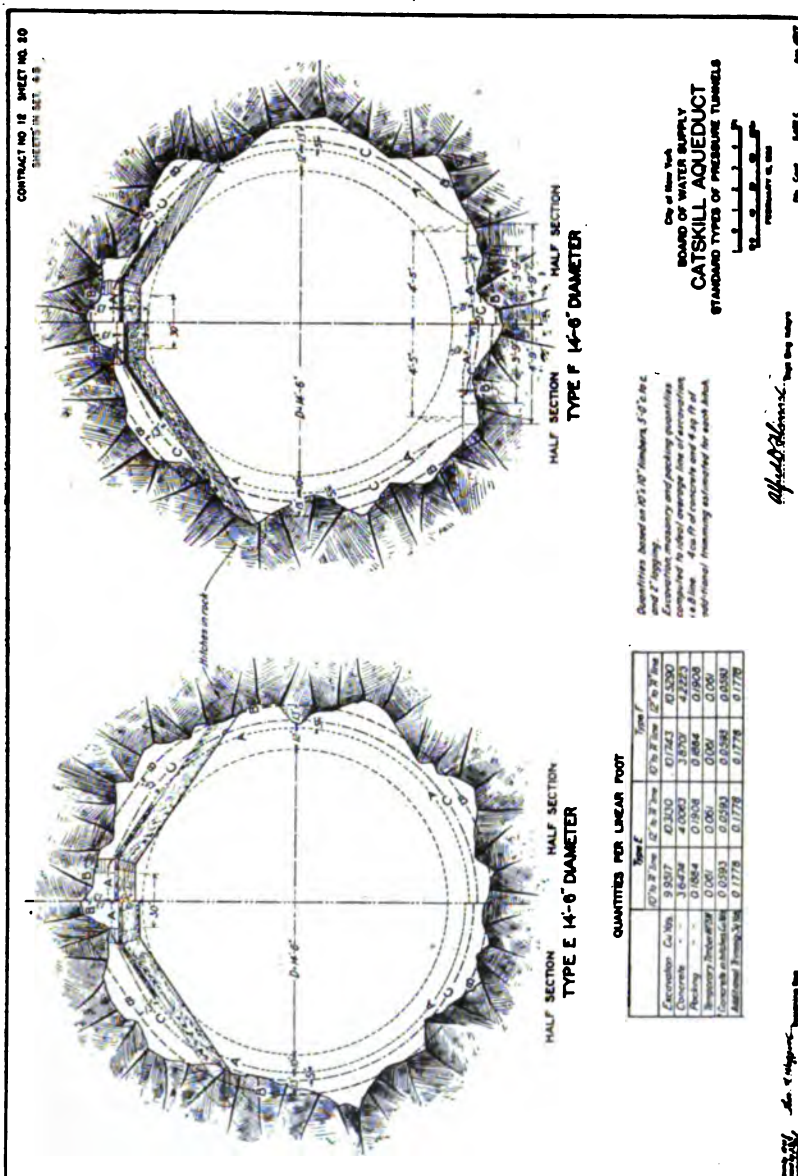


PLATE 14.—Cross-section of Pressure Tunnel Showing Section where Temporary Timbering is Used. Type "F," designed to be placed while excavation is in progress not used.

lic properties of the larger section, its lower unit costs of construction, and improved methods, the lower relative cost of the Catskill Aqueduct is in a great measure due to the substitution of cut-and-cover for grade tunnel.

Pressure Tunnel. The high level of the Catskill Aqueduct, and the difficult nature of the country traversed by it, greatly increase the proportion of aqueduct below grade, and have led to the great development of the pressure tunnel type which is the most striking feature of this work. Pressure tunnels have been used before on other work, but never in the magnitude or depth below hydraulic grade. They are used wherever practicable instead of steel pipes, on account of their permanency and greater economy when renewals and maintenance are considered.

Comparison between Aqueduct and Railroad Location. The comparison between aqueduct and railroad locations brings out the following: Both are linear structures designed to connect certain fixed points with the greatest economy practicable under the conditions. Railroad location is more of an economic problem, as it involves the balancing of economy in original cost against economy in operating expenses and maintenance. A railroad is susceptible of development and may be improved and enlarged to suit a growing traffic. The only economical way to enlarge an aqueduct is to build a new one. It is built for all time, and safety and permanence are therefore much more important factors. When it is considered that an aqueduct like the Catskill costs from eight to ten times as much per foot as an average double-tracked railroad, it will be seen that in a problem of location much more detailed study is justified and required. In a railroad location, grades can be changed to suit the topography, being governed only by economy in operation and maintenance. In gravity aqueduct location the grades are determined by the hydraulic gradient; to go above is impossible, and to go below involves additional expense. On a railroad, curves affect economy in operation and maintenance, while in an aqueduct they are practically almost negligible. Aqueduct location is quite dissimilar to railroad location, as aqueducts follow fixed grades and have not the same freedom to cross embankments or bridges, and it is dangerous to put them partly on cuts-and-fills at side hills. Safe location is the primary object, as leakage may lead to washouts of serious consequences in settled country. On the other hand, aqueduct location has a certain freedom in crossing wide valleys, using for "inverted siphons," pressure tunnels or steel pipes. By means of deep shafts and tunnels, the aqueduct may be brought below almost any valley, the only limitation being that the top of the uptake shaft shall be a proper distance below that of the downtake to force the water through.

Cost Curves. As soon as a decision was reached by the designing division on the size and shape of cut-and-cover, grade tunnel and pressure tunnel, the cost curves shown on Pl. 15 were prepared in the following manner: Unit costs were assumed for different classes of work and applied to quantities determined by planimetering typical sections. On the cut-and-cover sections, costs were thus computed for every 2-foot difference in center line elevation; for three different natural conditions, i.e., ground level, slope four on one, and slope three on one; and for five different subsurface conditions, i.e., all earth, all rock and earth overlying 4, 8 and 12 feet of rock respectively. The side slopes of the rock, when masked, were assumed to be the same as that of the surface. Cost curves were then constructed by plotting cost against depth of cut for the five different subsurface conditions on each of three different slopes, making fifteen different curves. By aid of these, it was possible to estimate costs very rapidly from trial center line profiles. Approximate costs of grade tunnels were also determined from assumed unit costs and planimetered unit quantities for three different conditions, i.e., (1) tunnel in sound rock, (2) timbered tunnel in rock, and (3) tunnel in earth. The figures thus obtained were used in comparing alternate lines of cut-and-cover and grade tunnel, and were also plotted on the cost-curve sheets to indicate approximately the depth of cut at which it would be economical to start tunneling. The estimated costs of pressure tunnels depended so much on positions of rock surface, character and position of rock strata and other conditions peculiar to each tunnel, that independent cost studies were made for each alternate location. A tentative linear foot cost was estimated for each pressure tunnel for comparison with alternate cut-and-cover, grade tunnel and steel-pipe locations. While the designs for steel and reinforced concrete pipes were not in final shape until most of the locations had been completed, an estimate of cost on a tentative design, very similar to the final one, was prepared for use in comparison with alternate locations of other types of aqueduct.

In preparing curves of this kind the absolute unit prices are not of as much importance as the relative prices. If, for instance, the relative price of excavation as compared to concrete is unduly low, the tendency would be to favor the shorter lines. Indeed, these curves show too low a cost for the type of aqueduct partly in rock,

ESTIMATED COSTS. CUT-AND-COVER AQUEDUCT. FOR SURFACES SLOPING—1 VERTICAL TO 4 HORIZONTAL. MADE IN CONNECTION WITH CATSKILL AQUEDUCT LOCATION:

Assumed Costs

Earth excavation	Cubic yard	$0.30
Rock excavation	"	1.50
Refill direct from excavation	"	0.30
Refill from borrow	"	0.50
Concrete including forms and cement	"	7.00
Surface stripping 1 foot deep	"	0.60
* Surfacing, smoothing, sodding, and seeding	"	Cost of refill plus 0.30
Rubble retaining wall	"	2.00
Fencing one foot along aqueduct	"	1.00

* Assumed for surface material 1 foot deep.

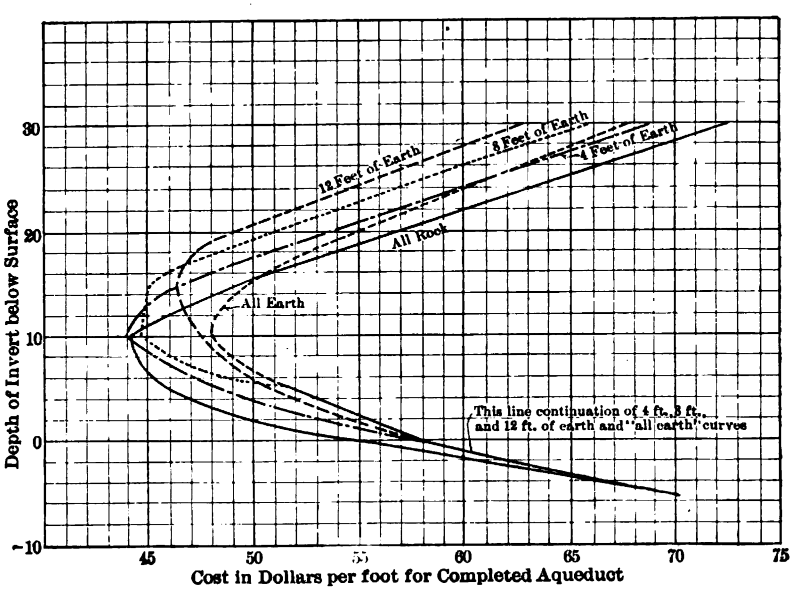


PLATE 15.—Cost Curves Used for Location of Cut-and-cover Aqueduct.

in some cases the cost being lower than aqueduct in all earth, due to the assumption that narrow cuts would be used through rock, the resulting saving of expensive concrete more than balancing the extra cost of rock excavation. This was realized in but few cases of actual construction. However, this assumption did not lead to any notable errors in location, as it was rarely possible to choose the kind of material the cut-and-cover aqueduct was to be constructed in.

Unit and Linear Foot Costs of Aqueduct. It is interesting to compare the original assumption of unit prices and linear costs with the prices for which the contracts were afterwards let. The original assumptions used on location of the Northern Aqueduct Department were as follows:

UNIT COSTS

CUT-AND-COVER

	Excavation per cu.yd.*	Refill per cu.yd.	Concrete per cu.yd.
Assumed price	$0.50	$0.30	$7.00
Contract price	0.58	0.30	7.30

GRADE TUNNEL

Assumed price	$5.50	....	$10.00
Contract price	5.17	....	9.15

* For earth. A price of $1.50 per cubic yard was assumed for rock. Under the contract there was no classification.

LINEAR FOOT COSTS

CUT-AND-COVER

	Excav.	Refill.	Concrete.	Culverts.	Misc.	Total.
Assumed price	$10.32	$5.00	$34.48	.....	$1.00	$50.80
Contract price	12.10	5.45	35.19	$1.70	2.90	57.34

ALL TYPES

	Cut-and-cover.	Grade Tunnel.	Press. Tunnel.
Assumed price	$50.80	$90.00	$120.00
Contract price	57.34	98.25	141.10

Preliminary Contract Prices. In connection with these costs it should be borne in mind that in contract price for tunnels certain contingencies, not generally realized, were provided for; as, for instance, heavier sections for poor ground, timbering, etc. General actual cost will probably be from 5 to 10 per cent less than contract prices. As stated before, it is of the utmost importance in determining location to have the price of the different types relatively correct, so that one shall not be unduly favored. Taking cut-and-cover as a unit, the following is a comparison of relative cost of other types, under assumed and contract prices:

	Grade Tunnel.	Pressure Tunnel.
Assumed cost	1.88	2.50
Contract cost	1.71	2.48

It is gratifying to see that the assumed contract prices are close enough to indicate that the locations made on this basis were correct.

Preliminary Reconnaissance Map. Prepare the contour reconnaissance map with more than the usual care, using a 10-foot interval or increasing the scale at certain points if it should be necessary. The general location can be determined on this map, using linear-foot costs for comparison of likely routes. The selection of these linear-foot costs from the unit cost curves should be more closely supervised by issuing standard tables, as was done with unit costs. In this way all radical changes of location can be eliminated. There will still remain alternate routes, the merits of which can only be decided by detailed surveys. Apart from this, the location will be pinned down to a narrow strip, the chief problem remaining being the most economical arrangements of curves and tangents to fit the ground.

Cross-section Contour Survey. For this purpose the writer would favor a 2-foot contour map instead of running profiles and fitting tangents in the field. This map should be prepared by laying out on the reconnaissance map a series of tangents, as close to the final location as can be determined. These tangents should then be approximately located and laid out in the field, stationed continuously and used as a base line from which to take cross-sections for 2-foot contours. The width of country to be covered will depend on the steepness of the slopes and the possibilities for alternate routes, and should be enough so that no additional surveys will be necessary. The minimum-cost contour and the contour limiting the down-hill location of the aqueduct, determined as previously described, should then be plotted on the 2-foot contour map, and the final arrangement of tangents and curves which will best suit the details of typography fixed by comparative cost estimate and the exercise of judgment. The line thus determined should then be laid out on the ground and again subjected to careful field inspection and analysis.

Refinements to be Avoided in Location. The main dangers of the above method are three-fold:

1. Following too slavishly the economic cut, which will result in an inordinately crooked location.

2. A failure to take proper account of field conditions.

3. A tendency toward over-refinement, spending too much time and money in consideration of relative advantages of lines which differ very slightly.

The first of these may be controlled by an attempt to straighten out the line after the final location has been made, giving proper consideration to the advantages of a shorter line and the advantages of eliminating curves. The second and third may be prevented by the exercise of proper judgment by the locating engineer and by the fact that he will be relieved of the details of fitting tangents in the field and will have more time for the study of general considerations.

Advantages of Map Location. The advantages of this method are as follows:

1. Less ultimate work and cost of surveys.

2. The cross-section surveys, the bulk of the field work, require little judgment and skill, and can be entrusted to low-grade men.

3. The work of fitting curves and tangents to the ground can be better done on a map than in the field, provided that proper consideration is given to conditions in the field. With all due respect to advocates of a strictly field location, there is no "eye for country" as good as a contour map.

4. Better record of work.

5. The saving of time, and avoidance of confusion and annoyance, by the greater ease of systematizing office work and records.

Grade of Aqueduct. The grade of the aqueduct is such as to use up a head of about 200 feet between Ashokan Reservoir and Hill-view Reservoir, in a distance of about 90 miles. This allowed an average fall of something under 2 feet per mile, after certain allowances for loss of head at the Hudson crossing and other points were made. The problem was how to make the best use of this head. Due to the aqueduct running diagonally across many river valleys it was necessary to use several types of construction. The cost per foot of these types varies greatly, the pressure tunnel being two or three times as expensive as cut-and-cover. By adopting steeper grades for the more expensive types, the cost of the whole aqueduct is reduced, as the quantities of excavation, concrete, etc., are decreased, in proportion to lessened area of waterway.

First Rough Location. With the aid of the geological survey maps, using approximate grades, the first rough locations were made from which the approximate length of each type of construction was determined. From an assumed average cost per unit of length for each type, comparative estimates were made of the cost of the aqueduct for various practicable slopes. It was necessary that these slopes be such that when multiplied by the lengths of each type the entire head would be consumed. By this method the most economical slopes could be arrived at by a few approximations, because of the narrow range of slopes practicable and the fact that costs are not affected appreciably by any but considerable changes. The problem at best was only capable of approximate solution, as the final locations made many changes in the relative lengths of the various types of construction.

Mr. Wiggin's Cost Curves. Thomas Wiggin, Senior Designing Engineer of the Board of Water Supply, devised an exact method of determining the relative slopes of different types of aqueduct construction, known as the method of tangents to cost curves. On a coordinate sheet, curves were plotted to show the variations in cost of each type of construction with slopes. When, as can be readily demonstrated, parallel tangents to each curve give gradients which use up the available head, the most economical slopes are obtained. Unfortunately, the curves had a tendency to flatten out, so that it was difficult to draw definite tangents to them. There was also a tendency to unduly favor steeper slopes for tunnels, as curves of tunnel cost plotted from fixed unit prices showed too great variations of cost in favor of the smaller diameters. Experience shows that due to heavy overhead charges of tunnels, which is practically a fixed quantity, and to the fact that a certain size of tunnel is desirable to secure freedom of operation, smaller tunnels have higher unit charges. Mr. Wiggin's method of cost curves was later used to determine the slopes of various types of construction on the Los Angeles aqueduct.

Location on Geological Survey Contour Maps. The first location studies were made on the United States Geological maps.

These maps, drawn to a scale of about a mile to an inch with 20-foot contours, are accurate enough for general locations, and have the great advantage over larger maps that they give a birdseye view of the whole country, enabling the plotting of alternate locations and the computation of their relative costs. Were it not for these maps, great stretches of the country would have had to be surveyed, broadcast, before any definite idea as to the best place to put the aqueduct could have been obtained. This would have meant either many years more of work on the preliminary locations with a great expenditure for surveys, or more likely, due to the limited time, the selection of a route much more costly to construct than the one adopted. This is shown by the Hudson crossing. After considerable work had been done on the location of a crossing at New Hamburg an extended study of the country west of the Hudson, as shown on the geological maps, revealed the possibility of an entirely different route with 16½ miles of inexpensive cut-and-cover as opposed to much more costly work on both sides of the river at New Hamburg, and showed that a much better crossing could be obtained in the neighborhood of Storm King, at an estimated saving of about $2,000,000. It was found that nothing paid as well as plotting on the geological maps as many possible locations as could be conceived, making rough comparisons of their relative costs. From these many locations a few of the most favorable lines were selected to be thoroughly studied on the ground.

Precise Levels. The importance of consistent and reliable elevations was early realized, and a precise level party was organized to establish bench marks convenient to the proposed work from the Catskills to and through the city and far out on Long Island. As a basis, precise bench marks previously established by the U. S. Coast and Geodetic Survey were found at various points, and secondary bench marks of the U. S. Geological Survey were also used; in some instances discrepancies between them were discovered. From these bench marks, lines were run along the roads adjacent to probable aqueduct locations.

Method of Leveling. At first the ordinary wye level with single wire and New York level rods with movable targets were used. Later it was found that a three-wire dumpy level with 10-foot self-reading rods gave much better results, and far greater speed could be obtained, several miles a day being commonly run, with a maximum speed along a railroad of 13 miles in eight hours work. The method of the three-wire level eliminates many sources of error, it being found that an ordinary well-made dumpy level gave results within the limits of error adopted by the Coast Survey. The establishment of levels in this manner was very economical, and furnished the work with a great number of convenient and reliable bench marks. All elevations were established on a common datum, i.e., mean sea-level at Sandy Hook as established by the Coast Survey. This was the first time that this datum was adopted for construction in New York and its vicinity, and by its use the confusion and discrepancies which would otherwise have resulted from the various datum planes commonly used at New York were avoided. From the bench marks established by the precise-level party, lines of levels were run along the contours near which the aqueduct was likely to be located. These level lines established by the locating parties really were the first rough aqueduct locations on the ground.

Location Survey by Stadia Methods. The next step was to make a transit and stadia traverse along the contour of the aqueduct. The stakes of this traverse were all carefully placed and marked and the traverses adjusted. Following this, a regular stadia survey was made, establishing contours from the stadia traverse and level lines. This stadia survey was made with plane tables either on the ground or notes were kept in a regular manner and subsequently plotted to the desired scale, usually 200 feet to the inch.

Sketch Board. As an aid to the plotting, the notes were roughly plotted in the field on a homemade sketch board handled in the same way as a plane table, the man operating it using his scale in the same way as the alidade of a plane table instrument. The sketches, usually plotted to a scale of 400 feet to the inch, saved a great many errors in plotting from the notes, and also helped very much to take shots at the points which really counted most. Without this, there are a great many wasted shots and a great liability to error in the subsequent plotting of contours.

Cross-section Method. Toward the end of the location work the cross-section method of locating aqueduct was used to some extent and is probably superior to that outlined above. By this method long tangents were established along the contour near which the aqueduct was likely to be. The P.I's of this traverse were carefully located as to elevation, and the azimuths and lengths of the courses established. The stationing was then established and cross-sections of the ground taken every 25 feet. These cross-sections can be taken either with the level and rod in the usual way, or by stadia. The surveys were then plotted to convenient scale, say 100 feet to the inch, and accurate contours established on the plotting. On the contour plan from which the final location is to be made, various feasible alternate lines were plotted in pencil, and from common points comparative costs of different lines computed. For this purpose the curves showing costs of aqueduct for different cuts and different side slopes and for varying proportions of rock and earth were invaluable. From similar curves estimates were also made, based on quantities of excavation and concrete necessary for different tentative lines. In many cases it was necessary to dig test pits along the line to establish the material in which the cuts were to be made; also to establish whether certain lines were safe or practicable.

Grade Tunnel vs. Cut-and-cover. In some cases the location of aqueduct lay between certain lengths of cut-and-cover and a shorter grade tunnel. The tendency was to favor the grade tunnel, as it usually shortened the aqueduct line considerably, unless, of course, there was a decided difference of cost in favor of the cut-and-cover.

Shallow vs. Deep Cutting for Aqueduct. There are two different ways of locating cut-and-cover aqueduct; one tends to approach that of railroad location, favoring shallow cuts and use of borrow pits to make up for deficiencies of refill; or an attempt may be made to exactly balance cuts and fills. The other is to favor deeper cutting by placing the aqueduct well in the hillside, eliminating embankments if possible, crossing streams higher up, and shortening the line by abruptly cutting across noses. The latter method leads to excess of excavation, usually disposed of by widening the covering embankments of the aqueduct. On its face, the cost is higher, but not nearly to the degree the figures seem to show, as excavation can then be done at lower unit cost, particularly as steam shovels have come to be in almost universal use. Even conceding a higher cost, the deep-excavation method is much the safer, and largely eliminates embankments, gives shorter culverts, and an opportunity to waste material unsuitable for cover embankments; it also provides concrete material from the deeper rock cuts. The final result is an aqueduct much less liable to leakage, as a good portion of it is likely to be below ground-water level.

Pressure Tunnel Location. Inspection of the route of the aqueduct will show that it tends to cross more or less at right angles many river valleys, the surfaces of these valleys being in most cases below hydraulic grade. In addition, this country has been glaciated, and each stream has a buried gorge where its preglacial predecessor flowed. These gorges are at all depths up to 700 feet below sea-level. Previous experience showed that it would be both dangerous and costly to attempt to locate a pressure tunnel in anything but solid rock, and it was determined to place the siphon tunnels so that they would have 150 to 200 feet of rock cover at the minimum. The siphon tunnels were favored, due to the remarkable success of the long Harlem River Siphon of the New Croton Aqueduct previously described, which has been in continuous operation for nearly thirty years without giving any trouble, with very slight leakage, and outlasting steel pipe lines laid about the same time. The locating of the lines of these siphons was by far the most important work of the aqueduct location, and in many cases determined long stretches of cut-and-cover leading to and from their uptake and downtake shafts. A superficial examination of the contours of the valleys and rock outcrops, although of considerable value, could not begin to be sufficient to determine their locations as to position and depth. This was realized very early in the work and contracts were let for borings in all the river valleys which had to be crossed. These borings determined the position and depth of the buried gorges and the rock structures which underlie them. This subject is treated separately, under Borings, Hudson River Crossing, etc.

CHAPTER IV

BORINGS AND SUBSURFACE INVESTIGATIONS

Borings of the Board of Water Supply. Although only incidental and preliminary to the main construction, the boring work of the Board, if combined, would have made one of the major contracts of the Catskill work, and probably the most important, as nothing but the shallowest surface work could be safely undertaken without the knowledge supplied by the borings. The work itself was accomplished through numerous agents, many machines were acquired or rented, and much work done directly by the Board, through their engineers, with skilled drill runners and laborers.

The bulk of the borings was made, however, by contractors whose services were obtained either by general contract or informal agreements. The payments for work so done were many hundreds of thousands of dollars, totaling to the close of 1910, 146,810 feet of core borings. The work accomplished along these lines far transcends anything done in connection with any other great engineering undertaking, being greatly in excess of similar work on the Panama Canal. For this reason, it warrants a separate chapter of this book.

Preglacial Topography along Line of Work. The country occupied by the reservoir and traversed by the Catskill Aqueduct must have looked very different before the glacial period. Then it must have been a country of much bolder relief, with many deep canyons occupied by streams now flowing near the surface. The advancing and receding ice filled all the gorges with drift, forcing many of the streams to different channels and entirely obliterating some. In addition, many glacial lakes were formed by the damming of streams, these lakes accumulating immense deposits, carried down by the heavy flood waters of the melting ice sheet.

Preglacial Gorges. As the dams occupy the sites of filled-in gorges and the aqueduct crosses in an oblique direction a great many streams, ancient and modern, including the mighty Hudson, it became necessary to thoroughly explore the rock floor and to recreate, as it were, the original topography along the aqueduct line and at the dam sites. It soon became apparent that the modern country, in general rolling, has but a superficial, and in many cases deceptive, resemblance to the old preglacial topography; and though it took but a short time to thoroughly map the present surface, it was a task of considerably greater magnitude and tediousness to reproduce, through the agency of the core drill, the ancient gorges and rock structure. In the most extreme instance, at Storm King crossing, the necessary surface surveys, including the rough Highlands, were made in a few months, while the borings were only partially completed in four years.

Dr. Berkey's Geological Work for Board of Water Supply. The whole problem cannot be better stated than by freely quoting from Bulletin No. 146 by Dr. Chas. P. Berkey, published by the New York State Education Department. Dr. Berkey has been from the start expert geologist for the Board of Water Supply and has worked along with the engineers, acquiring a thorough grasp of the practical problems involved in this work of exploration as well as their purely scientific aspects.

Dr. Berkey on Rondout Crossing. "It is sufficient at this point to call attention to the facts of the topographic map and point out only the most general physiographic features that may at once be seen to materially modify the simplicity of the line.

"For example, one has scarcely left the great reservoir, with water flowing at 580–90 feet above tide, before the broad Rondout Valley is reached, with a width of 4½ miles, nowhere at great enough elevation to carry the aqueduct at grade. If it is to be crossed at all, and it must be crossed to reach New York City, some special means must be devised. If a trestle be proposed, one finds that it would have to be 4½ miles long (24,000 feet), and in some places 300 feet high, and at all points large enough and strong enough to carry a stream of water capable of delivering 500,000,000 gallons daily—a stream that if confined in a tube of cylindrical form would have a diameter of about 15 feet.

"A steel tube might be laid to carry the water across and deliver it again at flowing grade, but here one is met with the fact that it would require a tube of unprecedented size and strength and if divided into a number of smaller ones the cost would be greater than that of a tunnel in solid rock.

"The other alternative is to make a tunnel deep enough in bed rock to lie beneath surface weaknesses and superficial gorges and in it carry the water under pressure to the opposite side of the valley. This is the plan that seems best suited to the magnitude of the undertaking and would seem to promise most permanent construction. But no sooner is this conclusion reached than it is realized that there are now several hitherto unregarded features that assume immediate and controlling importance. Some of these, for example, are (1) the possibility of old stream gorges that are buried beneath the soil, (2) the position of these old channels and their depth, (3) the kinds of rock in the valley, (4) their character for construction and permanence, (5) the possible interference of underground water circulation, (6) the possible excessive losses of water through porosity of strata, (7) the proper depth at which the tunnel should be placed, (8) the kinds of strata, and their respective amounts that will be cut at the chosen depth, (9) the position and character of the weak spots with an estimate of their influence on the practicability of the tunnel proposition. Then after these have all been considered the whole situation must be interpreted and translated into such practical engineering terms as whether or not the tunnel method is practicable, and at what point and at what depth it should cross the valley, and at what points still further exploration would add data of value in correcting estimates and governing construction and controlling contracts."

Moreover, as Dr. Berkey states, "They do not become any easier simply to know that they *must ultimately be stated in terms precise enough for the use of engineers* and to know, furthermore, that the *real facts* are to be laid bare when construction begins and as it progresses."

Value of Geologists' Reports. It was early seen that mere general statements of geologists based upon outcrops, etc., were of little use toward determining precise location, or depth of tunnels, etc., and that it would be necessary to know the precise thicknesses, depths, etc., of the various strata penetrated by shafts and tunnels, also the precise width and depth of buried gorges to be blocked by dams and bored beneath by tunnels. The reports of the geologists in advance of borings, however voluminous, entertaining and replete with geological knowledge, were of aid only in guiding the engineers as to the placing of borings and warning them what to look for. As the work progressed, the geologists were called upon more and more to interpret the borings, prepare profiles from them, and to advise as to what new holes were necessary, etc. In this connection their services were invaluable, as their advice was not only of great aid to the placing of new holes, but served as a valuable check on the conclusions of the engineers. In this respect the benefit was mutual, the geologists becoming engineers (Dr. Berkey in particular) and the engineers something of geologists with their long dormant interest in these questions revived.

Strata in the Rondout Valley. To illustrate the value of a systematic exploration by borings no better place can be chosen than the Rondout Valley. Here there is a great variety of strata, and as great a complexity of structure as could be deciphered with any degree of certainty.

"Probably in no region of like extent is it possible to construct a geological cross-section of so many complex features so accurately as can now be done of the Rondout Valley along the aqueduct line. The section is known or can be computed to a total depth below the surface of 1000 feet, including 12 distinct formations, so closely that any bed or contact can be located within a few feet at any point throughout a total distance of over 4 miles."

According to Dr. Berkey the following formations are penetrated by the Rondout Tunnel:

	Feet in Thickness.
Hamilton and Marcellus flags and shales	700
Onondaga limestone	200
Esopus gritty shales	800
Port Ewen shaley limestone, including the Oriskany transition	250
Becraft crystalline limestone	75
New Scotland shaley limestone	100
Coeymans limestone	75
Manlius limestone, including Rosendale, Cobleskill, and the cement beds	100
Binnewater sandstone	50
High Falls shale, including small limestone layers	75
Shawangunk conglomerate	250 to 350
Hudson River slates—thickness unknown; probably more than	2000
Approximately	4775

Author's Comments. My own observations and comments on the geology and structures of the Rondout Valley and its bearing on the construction are as follows:*

Importance of the Geology of Rondout Valley to the Work. It would be hard to find, except in mining work, another instance where the geology of a region has been of such importance as in the location of the Rondout Siphon. In the Rondout Valley are many rocks differing widely in character and varying from the hardest millstones to the softest shales. These rocks, all sedimentary and

*Proceedings 1911, Paper No. 65, Municipal Engineers.

originally deposited in level beds, are now tilted up at various angles, and folded and faulted in a complex way, but still capable of being correctly interpreted from outcrops and borings. In addition, the rocks and depressions are buried under a deep mantle of glacial drift. In fact, two glacial gorges were believed to be present.

Lesson of the Loetschburg Tunnel Disaster. Some of the best geologists were engaged to examine the locality, and from outcrops and other data a profile was worked up. This proved to be of great aid in subsequent investigation, but was qualitative rather than quantitative. It gave a good idea of what to look for, but no definite location could be made, as the thickness of the various strata and the depths of the buried gorges had to be worked out by diamond-drill borings. Finally the contract profile was developed and confidently believed to be nearly correct. The borings took a great deal of time and were expensive, but the resultant certainty of location and foreknowledge of conditions to be met amply repaid the expense and time. In a deep tunnel of this character, it is considered absolutely necessary to keep the tunnel in solid rock and not let it penetrate the drift of filled-in gorges. A depth of at least 150 feet below the lowest point of these gorges was considered safe. The Loetschburg Tunnel illustrates well the enormous cost and disastrous result of running into a gorge. The Kandar River was to be passed at a safe depth in solid rock, but an estimate of geologists based only on superficial evidence was used, no borings being taken. When about 600 feet below the river, soft, water-bearing drift was struck, which quickly overwhelmed twenty-five men, filled up the tunnel and caused the abandonment of over one mile of it. Subsequent borings showed that the gorge extended far below tunnel grade, and that this fact could have been very easily determined in advance. It speaks volumes for the thoroughness of the Board of Water Supply work when we consider that despite the many streams which have been passed, no disagreeable surprises of this nature have yet occurred.

Growth of Geological Knowledge through Borings. To show the difference between our knowledge of the rocks of the Rondout Valley and the growth of this knowledge with the progress in boring, the data shown on Plate 16 were prepared, reproducing the various interpretations of the stratifications as the boring work progressed. It will readily be seen how imperfect the original information was and how the complicated folding or faulting had to be introduced to correctly interpret the borings. In particular it will be noted that the two preglacial gorges reversed the assumed depths, the deeper

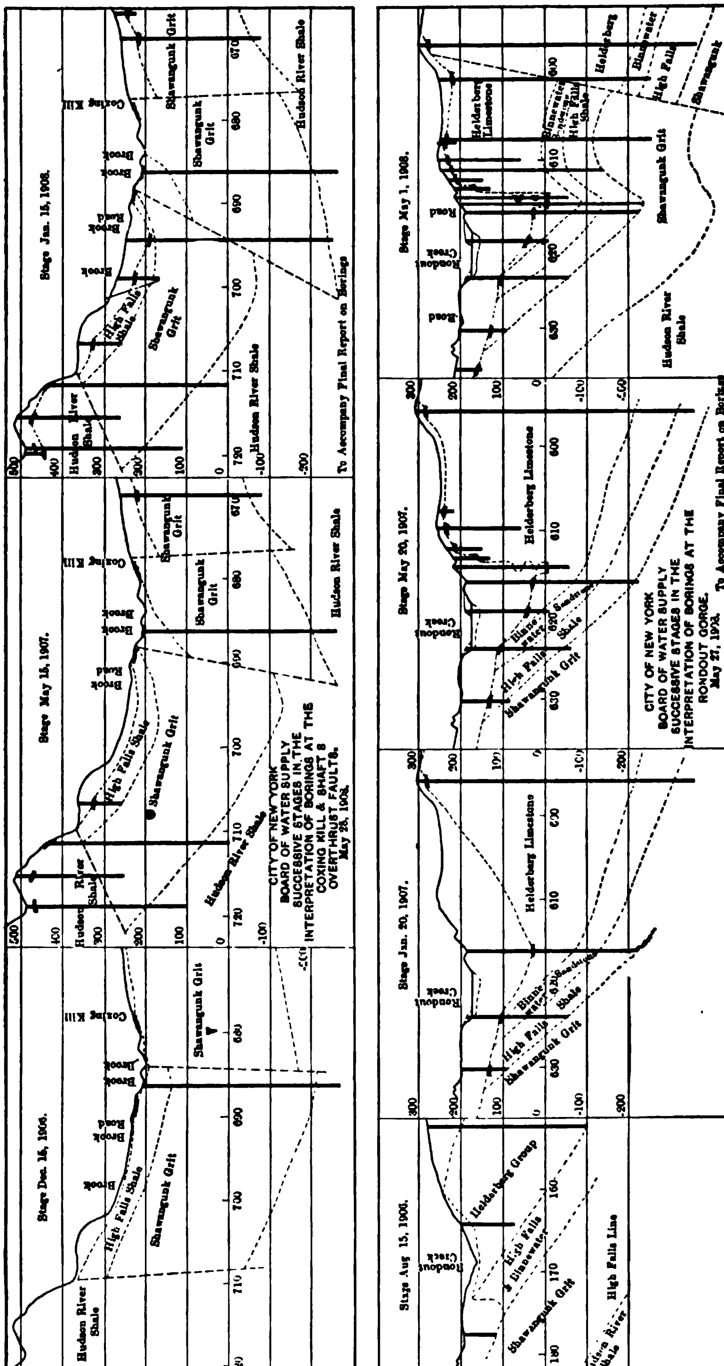


PLATE 16.—Tentative Profiles as Deduced from Borings while Exploring for Rondout Siphon. Shows successive stages in interpretation of borings and discoveries of faults and folds not previously suspected.

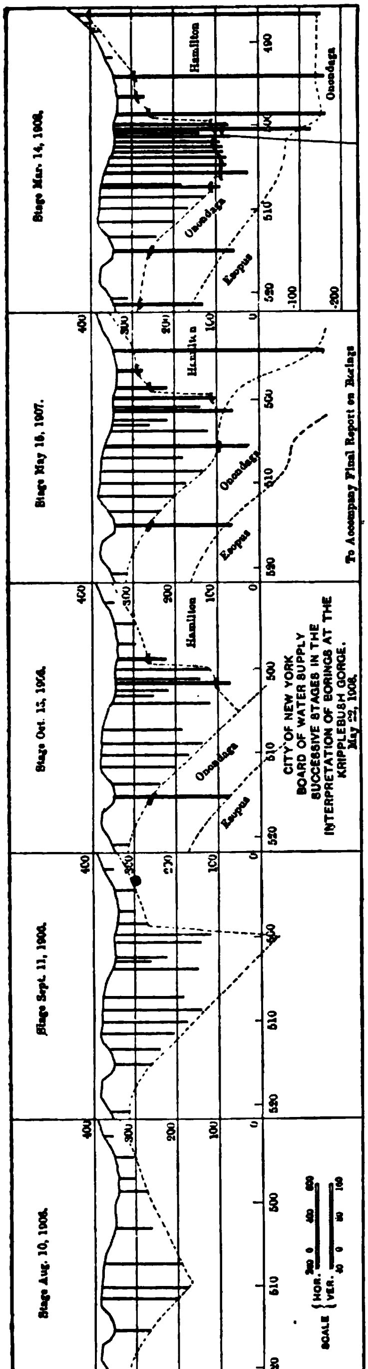


PLATE 16.—*Continued.*

one being near Shaft 4, instead of between No. 1 and No. 2, as originally supposed. The tunnel showed the stratification only slightly different from that given in the contract profile.

Value of Geological Generalization. The lesson to be learned from the above is that detailed knowledge of any particular location is necessary for engineering structures, and that generalizations from previous knowledge and studies are dangerous guides, particularly when the rocks have been studied in distant places, even though they are so-called type localities. It has been shown here that studies made before this work at places only a few miles away furnished very misleading conclusions when applied to the neighborhood of the Rondout Siphon. Also that little reliance is to be placed on descriptions of geologists, unless based on exact knowledge in the location of the work in question.

Tentative Profiles of Rondout Valley. During the boring operations many tentative profiles, Pl. 16, were drawn up for the purpose of locating new holes. One after the other they had to be modified from a simple profile originally assumed to the rather complex one finally adopted. Had the siphon been located from any but the final assumed section, many unexpected difficulties would have been found in shaft-sinking and tunnel-driving, which might have had the effect of seriously delaying the work and increasing the expense of construction. No conditions have been found in either shafts or tunnels which differ materially from those expected.

Salient Features of Rondout Geology. Reference to Plate 78 reveals the following salient features: Two buried river gorges, one at Rondout Creek reaching sea-level; the other, below Shaft 1, at elevation +100; also the bed of Shawangunk Grit reaching elevation −250 near Shaft 7, and several well-determined faults. Due to the great head of water on the walls of the tunnel at Rondout Creek (an unbalanced pressure of 300 ft.) it was decided not to allow any portion of the tunnel to approach closer than 200 feet to the low points in the rock profile. It was also decided to avoid the Shawangunk Grit as much as possible, due to the expense of driving through this very hard rock and the danger from leakage through open seams and fractures in this bed. Consequently, north of Rondout Creek the tunnel was placed at −100 feet elevation, and south at −250 feet. The next problem was to locate the shafts. Shafts Nos. 1 and 8 are the downtake and uptake shafts respectively, and are so located as to give the shortest siphon across the Rondout valley consistent with a good location of the aqueduct south and north.

Assumed Rates of Progress for Rondout Siphon. After considerable investigation, rates of progress for tunnel-driving and shaft-sinking in the various rocks were assumed, and the shafts located so as to give the time to finish this contract in about fifty-four months, or in about the time that a portion of the Ashokan Reservoir was to be available. Eight shafts as located gave the required results. The assumed rates are as follows:

Shale tunnel	120	feet per month
Grit	60	"
Shale shaft	40	"
Grit shaft	20	"

Experimental Tunnels. As very little was known about the drilling and tunneling qualities of Shawangunk Grit, as compared with ordinary rocks, two experimental tunnels were driven near Shaft No. 8, one in Hudson River shale and one in Shawangunk grit. Due to a fault, both these rocks lie side by side and the tunnels were driven by means of one steam plant. Although only 100 feet of tunnel was driven in each rock, valuable results were obtained, as skilled tunnel men were readily obtained by the contractor,

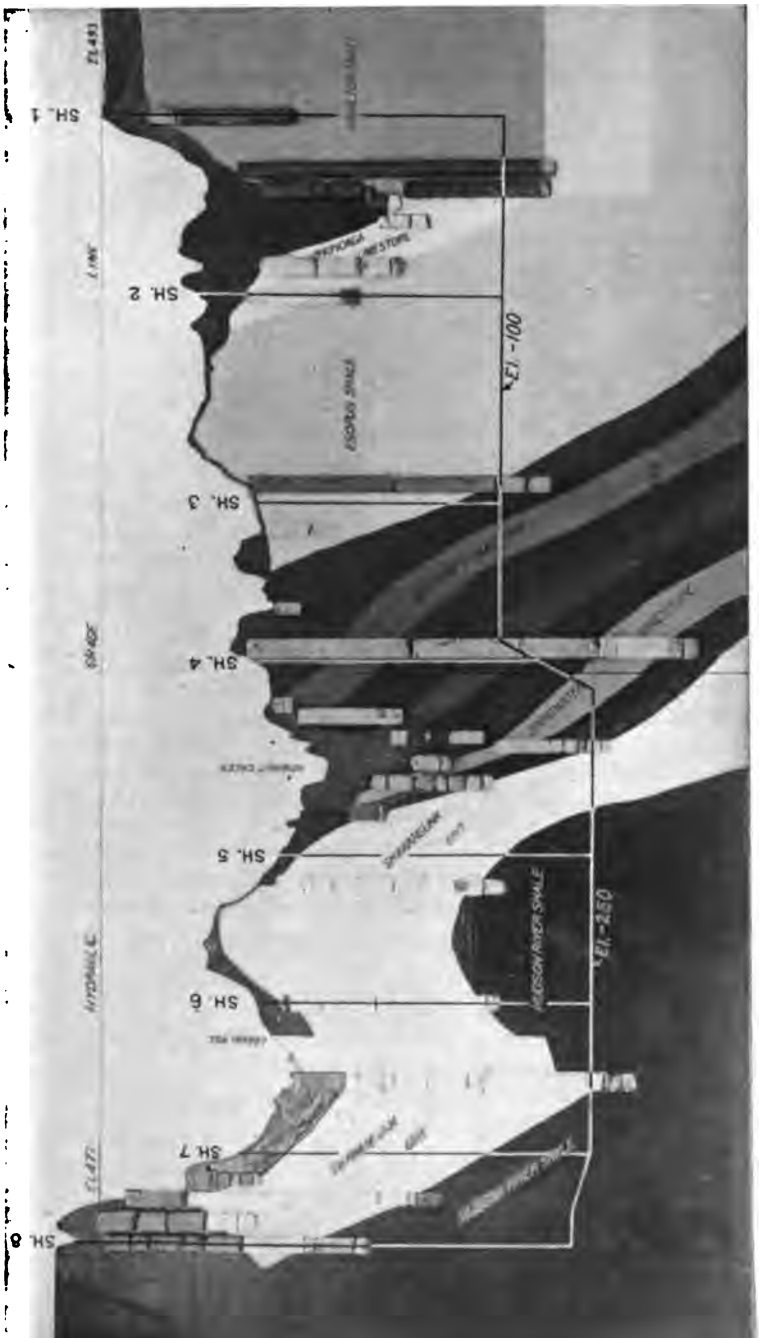


PLATE 17.—Core Board Profile of Rondout Siphon; Diamond Drill Cores Shown in Relative Position from which they were Obtained. Fault and Fold at Shaft 4, as shown in Plate 78, was discovered after Core Board was made.

Naughton & Co., from the neighboring Rosedale cement mines. At the expenditure of only a few thousand dollars, information was obtained which materially aided in the location of the tunnel. The conclusions reached have been amply borne out by the work in the Rondout Siphon.

Relation of Rondout Problems to Others. What has been said about the Rondout will sufficiently illustrate the problems of the other pressure tunnels, although each is sufficiently important to warrant separate treatment, but it would unduly lengthen this book. The problem of the Hudson crossing is of such special interest that it will be separately treated.

Exploratory Work for Grade Tunnels. For the grade tunnels, it was necessary in most cases to merely determine the materials at the portals and the nature of the rocks to be penetrated. In some of the larger grade tunnels, as the Garrison, conditions similar to pressure tunnels had to be determined and overcome. The longer the crossing of a valley the more likely is the pressure tunnel to be adopted, as then the cost of the shafts does not make relatively such a large proportion of the total cost. To cross a narrow gorge the shaft may have to be as deep as in a wide one and the cost then becomes too great to stand comparison with steel pipes, even when allowance is made for the latter's shorter life.

Peekskill Creek and Foundry Brook Siphons. It was for some time undecided whether the Foundry Brook or Peekskill Creek siphons would be built as pressure tunnels or steel pipes. The rock, as determined by borings, appeared to be of such poor quality that the pressure tunnel location was abandoned in favor of the steel pipes.

Tunnels versus Cut-and-cover Aqueduct. In general, it may be stated that the difficulties of tunneling are met mostly in the preliminary stages of location and during construction. Once built, they cease to trouble and, granting proper construction, their maintenance cost is small. For this reason, the cut-and-cover aqueduct is not in the long run as economical a construction as it appears in the first instance, as miles of embankments, fences, culverts, etc., have to be maintained on the surface where they are exposed to the elements. Grade tunnels are, of course, due to absence of shafts, much cheaper to build than pressure tunnels. They also have small maintenance charges and have the advantage that they can be easily inspected. In mountainous and hilly regions, in particular, they tend to greatly shorten the line and to eliminate doubtful and extreme types of cut-and-cover aqueduct.

Geology of Ashokan Reservoir. The great glacial deposits in the vicinity of Olive Bridge on the Esopus alone made it practicable to construct a reservoir at anything like elevation 600. Were it not for these impervious deposits of glacial till the crest of the dam could hardly reach elevation 450, which is 50 feet below the invert of the aqueduct as constructed. Esopus Creek was rudely treated by the glaciers, having been forced to carve new channels for itself more than once. These gorges could only be discovered by borings. The engineers, before definitely locating the dam, were most anxious to ascertain the character of the glacial drift which would have to be relied upon to act as a natural auxiliary to the structure to be built and to furnish secure foundation. In addition, it was necessary to determine the locations and depths of the buried gorges of the Esopus and other streams in so far as they might affect the construction or location. Dr. Berkey gives the following account of the geologic history of the Esopus Valley:*

Preglacial Esopus Creek According to Dr. Berkey. "In preglacial time the Esopus Valley was occupied by a stream of similar capacity to the present Esopus Creek. Its channel lay to the north side of the narrow valley, having adjusted itself in conformity to the slight dips of the Hamilton sandstones and its principal joints. At the points under investigation this original channel is buried under several kinds of glacial deposits whose source of accumulation was chiefly from the north and northeast, blocking the stream channel and forcing the stream to the opposite (south) side. The direction of movement was favorable to the damming of the Esopus Creek Valley, and the deposits indicate that this occurred at several different times and at different elevations and that corresponding lake conditions occasionally prevailed. It is equally clear that there were intervals of retreat of the ice with attendant stream action and the development of gravel beds, followed by another ice advance, either obliterating the surface features or covering the previous deposits with another till layer. With each successive withdrawal the local streams found themselves more or less completely out of place, and consequently their characteristic deposits formed in these intervals may be found in unlooked-for places wholly inconsistent with present surface contour.

"At the final withdrawal of the ice, Esopus Creek found itself intrenched along the southern margin of the valley and has cut a

*Bulletin 146, N. Y. State Education Department.

postglacial rock gorge, instead of removing the compact till from the original channel. But wherever only modified drift, either sand or clay, was the valley filling, it scooped out great bends, so that a large proportion of this type has been removed from the valley, and only the margins remain as terraces or covered beneath other protecting deposits."

Tongore Dam Site vs. Olive Bridge Site. From surface indications, there were two excellent dam sites for the Ashokan Reservoir, one at Tongore, the other at Olive Bridge. Surface topography appeared to favor the Tongore site, as, although the main masonry dam would be 290 feet high as against 210 for Olive Bridge, the total length of dam and dikes would be only 2 miles against 3.8 miles for Olive Bridge. In addition the Tongore site could furnish more watershed by 6 square miles, besides shortening the Catskill Aqueduct more than 2 miles, and eliminating two troublesome pipe siphons at Esopus and Tongore creeks.

Borings at Tongore Dam Site. Surface indications are, however, often deceptive, and are not to be trusted to point out safe dam sites. On the south bank of the Esopus good rock outcrops were found and the rock in the river bed appeared to be sound bluestone and shale without water-bearing streams. One boring, however, happened to straddle a narrow seam (less than 1 inch thick). This was followed from 90 feet below river bed to 104 feet, the core brought up showing both sides of seam and much iron pyrites. The seam yielded water under pressure which rose 10 feet above top of casing. This flow, although constant, was not considered of great importance owing to the great depth of sound overlying rock.

North of the dam site lies a long high ridge which alone makes a tight dam at the Tongore site possible. This ridge was thoroughly explored by borings.

About 2000 feet to the north of the present gorge, an older channel, supposed to be the preglacial course of the Esopus, was discovered. This had been cut to elevation 250 feet, about 60 feet lower than the present stream. Over it was 10 to 150 feet of water-bearing sand and gravel, and above this a surface coat of 100 feet of impervious glacial drift. The water-bearing character of the sand was indicated by the loss of wash water in the borings as soon as the wash rods reached its level.

Test Shaft at Tongore Dam Site. To obtain definite data, a shaft was sunk by contract with Naughton & Co., It was $16' \times 24'$ in plan and protected by $12'' \times 12''$ timbers and 3-inch sheeting.

The material for the shaft was piled up carefully and so spread out upon the ground as to indicate plainly the depth from which it was obtained. The impervious top drift (depth 87 feet) was readily penetrated, but below this the water-bearing ground above mentioned gave great difficulty, the water increasing from 10 gallons to 160 gallons per minute at a depth of 114 feet, when the shaft was abandoned. Indications were, therefore, very strong that a subterranean water passage or porous zone of considerable extent existed. To make this site safe, a core wall 1400 feet long would probably have had to be built to rock at an almost prohibitive cost, as its height would have had to be at the maximum 250 feet below ground and 150 above. Due also to the small cross-section of the ridge on which the dam would have had to be founded, there would have been considerable danger of the water escaping below the dam.

Supplementing borings with data obtained by shafts at the critical points is much to be commended, as materials washed up by borings have a strong tendency to indicate too much sand and gravel, the finer particles of clay being wasted with the wash water. Unfortunately, shafts are expensive, and as it takes considerable time to sink them, it is not feasible to have many, but they serve as a decided check on the materials and interpretations of wash borings.

Olive Bridge Dam Site. The Olive Bridge site when thoroughly explored by numerous borings and several shafts gave nothing but favorable indications. The glacial drift overlying the rock is of a dense impervious nature (boulder till) extending down to rock over which there is no intervening porous layer, as at the Tongore site.

For the following reasons, the Olive Bridge dam site was chosen:

Dr. Berkey's Reasons for Recommending Olive Bridge Dam Site. "Because of the (*a*) higher bedrock throughout, and (*b*) the more uniform and impervious quality of drift deposits, and (*c*) the more massive cross-section of drift barrier for foundations, and (*d*) the perfectly tight contacts of till and bedrock, and (*e*) the limitation of the more porous materials to higher levels, and (*f*) the glacial history connected with the development of all these parts, 'Olive Bridge' is the preferable location for the proposed Ashokan Dam on Esopus Creek."

Rock Profile at Olive Bridge Dam. The profile along the center line of the dam, shows clearly what has been stated, that rock is the foundation of the dam for only a small portion of its length. Two preglacial gorges have to be crossed. The old Esopus gorge, about 50 feet below the modern gorge and about 1000 feet to the north, lies below a drumlin of impervious material known as Winchell Hill. No effort will be made to go below it, as it is crossed by a core-wall dike founded on the overlying impervious drift.

Beaver Kill Preglacial Gorge. A very interesting gorge was found under the present Beaver Kill, a sluggish stream which no one would suspect of possessing any particular energy past or present. Yet it had carved a gorge about 100 feet below the present bed. As it was excavated for the purpose of blocking it with an arched core wall, a perfect trapezoidal cut was exposed, sloping regularly downward from one bluestone ledge to another, both sides being very symmetrical. Under each ledge is a soft layer of shale. The bottom material was supposed to be water-bearing, but no difficulty was experienced in the excavation. It was simply a loose boulder till with much gravel and enough fine material to hold back the ground water, which reached the cut only in small quantities. Subsequent excavation has amply confirmed the borings and preliminary investigation; everywhere the glacial material, upon which most of the dam is founded and with which the greater dikes were made, proved to be impervious and admirably adapted to the purpose. See Plate 49.

Summary of Subsurface Investigations at Ashokan Reservoir. To illustrate the amount of work done, there was available for the information of intending bidders on the dam and dikes the following records: B. W. S. Report for 1907:

" 270 borings, aggregating 29,480 feet.

" 169 test pits, trenches and shafts from 5 to 155 feet deep.

" 214 pits in sand deposits.

" Sixty-four of these holes were in quarries to show character of rock available for the work. They aggregate 512 feet in earth and 2385 feet in rock.

" Prior to the arrival of prospective bidders to look over the ground, the entire line of dams and dikes was staked out and the location of each boring marked. The detailed boring records, samples of materials penetrated, and cores of rock were on exhibition at the office. Test pits and shafts were open, and the material excavated therefrom was ready for inspection, and photographic records showing the material encountered, were at the service of bidders. Various trenches down the face of steep bluffs were exposed, test pits in several sand deposits could be inspected, borings at various possible quarry sites were indicated by signs, cores were displayed at the office and the boring records were in convenient form for the contractors to study. Boring records and samples from possible borrow-pits were also on exhibition."

River Control at Dam Site. To show as fully as possible the character of the river bottom at the dam and to gain time, after the letting of the contract for main dam, river control works were constructed directly by the Board, J. F. Sanborn being in charge under Department Engineer C. E. Davis.

Two timber-crib, rock-filled cofferdams were built across the stream 400 feet apart and two 8-foot steel pipes installed between them. The cofferdams, headworks and pipe foundations were built by the forces of the Board. The two steel pipes were furnished and laid by the T. A. Gillespie Company. The stream flow was turned into the two pipes and the space between the cofferdams unwatered. Loose material was removed from the bed of the creek and the rock exposed for examination. Besides giving a correct idea of what the river bottom is, it enabled the contractor the following year to immediately begin the work of excavating the foundations of the dam between the cofferdams and saved a full working season. The pipes did their work perfectly, except when one freshet temporarily flooded the excavation, which was anticipated.

Boring Machinery Used in Reservoir Department. In the Reservoir Department borings were made both by the forces of the Board of Water Supply operating city-owned drilling outfits and by contractors for wash borings to determine the depth of surface materials. Small outfits were used, consisting of derrick, hand pump, wash and drive pipes, etc. The complete drilling outfits used by the Board of Water Supply consist of portable boiler, derrick, steam pump, Badger screw-feed drill made by the Sullivan Machinery Company, drill rods with equipment of core barrel and diamond bit, wash pipe, chopping bits and necessary tools and fittings. The contractors, Sprague & Henwood, of Scranton, Pa., used a similar outfit, except that they operated several large hydraulic-feed diamond drills made mostly by Sullivan Machinery Company. In general in the reservoir department the main difficulty was to reach ledge rock with the casing through which the boring in the rock was subsequently made.

Getting Casing by Boulders by Chopping and Blasting. The greatest difficulty in boring is that caused by boulders. When a boulder is reached too large to be chopped through, dynamite is lowered into the casing resting on the boulder. The casing is then pulled up a few feet, the dynamite exploded by means of magneto and battery wires. Repeated blastings may have to be resorted to before the boulder is sufficiently broken to allow the casing to pass. A large boulder may not yield even to this rough treatment, but it may become necessary to drill a hole into it with the diamond drill, after which more dynamite is lowered into this hole and the boulder shot into bits. It sometimes happens that if the casing is not pulled up high enough the dynamite will split it, so that when it is attempted to drive it down again it will collapse, thus spoiling the hole. The various difficulties encountered by drills will be described more at length later.

Details of Diamond Drilling. After the casing is well seated on the bedrock, the rock drilling is carried on as follows: Specially heavy diamond-drill rods with square threads which may previously have been used as wash pipes are connected and lowered to the rock. To the lower end of this line of rods is screwed a core barrel about 10 feet long to which in turn is fastened a short core shell containing the diamond bit. The diamond bit is a soft steel pipe about an inch long, one end screwed into the core shell, the other turned square and having embedded in it two rows of diamonds. All the diamonds project slightly from the metal, those on the outside so as to cut a hole in the rock large enough to receive the core barrel, those on the inside so as to cut a core to pass through the bit and core shell into the core barrel. At the bottom of the core shell is a hard metal spring with upward-facing teeth which allows the rock core to pass upward but not downward. The upper end of the drill rod is passed through the drill, and the steam pump is connected with its top by means of a rubber hose and water swivel. The drill rods are then revolved in the same manner as an ordinary drill press and the rods are fed downward as fast as the core is cut, by one or two methods—either by a screw-feed as in the Badger drill, which is adjustable for different rates of cutting, or as in hydraulic machines, by a hydraulic cylinder and piston, through which the drill rods pass. The pressure of water maintained by the steam pump forces the rods downward as fast as the diamond bit cuts. It also gives the proper pressure for the best operation of the diamonds. In case of long lengths of rods, the hydraulic machine may be so controlled as to partly balance the weight of the rods, preventing excessive pressure on the diamonds. The diamonds are, however, remarkably strong and able to stand a heavy steady pressure, no difficulty being experienced in getting a few small diamonds to support as much as 600 feet of heavy drill rods. While the drill is being rotated water is forced, under considerable pressure, through the rods, clearing away the chippings from the bit and keeping the bit cool. If there be any interruption of the supply of cooling water the diamonds become too hot and the bit is liable to fuse, in which case the hole may be lost, with the diamonds.

Efficiency of the Diamond Drill. The diamond drill is a remarkably efficient tool, and were it not for the heavy cost of the black diamonds used would be much more extensively employed. It has been used now for such a long period that the present drills are as well made and reliable as almost any machine-shop tool. There is a tendency to exaggerate the diamond loss in drilling and the value of diamonds lost in bits not recovered. The experience on the Board's work would indicate that one bit is lost to about every 10,000 feet drilled. Valuing a bit at the high cost of $1000, this would mean a charge of 10 cents per foot. In addition, the diamond loss may run from a few cents a foot to 50 cents or more, depending on the hardness of the rock. The writer is aware of no other machine capable of boring rock and yielding core which can be depended upon to make the progress and to penetrate rock of any nature, hard or soft, seamy or compact.

Contract Boring at Ashokan Reservoir. The linear feet of borings made in the Reservoir Department has previously been given. The contract prices were $3 to $4 per foot for core borings, but the cost of the direct work was somewhat less. The rocks bored into are the Hamilton beds of the Devonic Era and consist of alternate layers of sandstone (bluestone) and shale, which offer no great difficulty to boring.

Borings in Northern Aqueduct Department. Undoubtedly the most difficult drilling of the entire work was that necessary to determine the location of the 17.25 miles of aqueduct below grade in this department. In addition, some work was necessary to determine the material to be penetrated by the 6⅓ miles of grade tunnel beside some work for the 36⅓ miles of cut-and-cover. But the latter could usually be determined by test pits, except in the very deep earth cuts where borings were necessary. The one great problem of this work, of course, was that of the Hudson River crossing, and this has stood out so conspicuously as to obscure the subsurface investigation necessary for the other siphons.

Rondout Siphon Borings. The work of this character on the Rondout Siphon has already been referred to. Here the greatest difficulties encountered were in the deep deposits of glacial drift over the preglacial gorges. Between Shafts 1 and 2 over 250 feet of drift had to be penetrated, some of it bouldery; but the greatest difficulty was experienced in penetrating a slatey gravel which packed at the bottom of the casings and was very difficult to wash out even with chopping bits. The work on this siphon was performed under various agreements with Sprague & Henwood, and directly by the Board's forces, the prices varying between $2.35 and $6 per foot. It was early found that the Shawangunk grit was difficult and costly to drill—a small screw-fed machine only averaging 2 to 3 feet per eight-hour day—and so wearing the diamonds (" polishing the bits ") that it was necessary to reset the stones daily. Later, the contractor would not do work in this bed under $6 per foot, but it was found that by the use of a heavy hydraulic machine (Sullivan " B ") 6 to 8 feet per day could be secured with much less diamond loss per foot than with the light rig. It was explained that the light rig merely rotated and " polished " the diamonds against the quartz pebbles of the conglomerate, not getting sufficient pressure to do much cutting. With the hydraulic machine heavy pressure could be brought to bear, cutting the rock at the same time the machine rotated. The wear on the diamonds was of course large, a bit needing resetting each 6 to 8 feet. The projecting edges of the diamonds were worn off, so that to cut at all new faces had to be exposed, giving the necessary clearance. The diamond losses in these holes averaged probably about 50 cents per foot, but in exceptional cases where seams were penetrated diamonds would be torn loose from the bit or shattered. In all hard drilling it was noted that good, well-tested black diamonds give a much smaller loss than those of cheaper and poorer grades, so that it is true economy to have the best diamonds in the bits, even at the risk of their total loss due to some seam or cave or other unforeseen condition. Black diamonds from Brazil are used. Before being placed on the market the stones are crushed and large pieces (1–2 carats) with sharp edges selected. They are worth $40 to $75 per carat, according to size and grade of the individual stones, and are two or three times as expensive as they were in 1895. It takes a good deal of experience to select a stone, as some will soon shatter under use while others will wear very slowly and stand a great many resettings. It follows that tested diamonds which have been used in bits are worth a great deal more than new stones.

Borings Made by City-operated Machines. The first wash boring machines at work along the line of the aqueduct were owned by the City. They were only able to put down a single line of 2½-inch casing, and it was soon found that heavy glacial material could not be penetrated with any success. Boulders would stop the casing as effectually as ledge rock and misleading reports as to rock surface

PLATE 18.—Sullivan Hydraulic Diamond Drilling Rig at Shaft 8, Rondout Siphon.

thereby resulted. In some cases the rock was found 100 or more feet lower than was indicated by the boring. Wash borings with hand rigs are useful only in those localities where deposits of soft material, as sand and fine gravel, are found.

Steam Boring Machine Built and Operated by City. Later a steam rig was designed and built at Brown's Station by the forces of the Board of Water Supply. On a heavy wagon, a vertical boiler, steam pump, small steam engine operating a derrick and walking beam were mounted. This machine had sufficient power to handle long lines of casing and the walking beam enabled the wash rods to penetrate hard material. With this machine holes were put through the heavy, difficult ground of the buried gorge between Shafts 1 and 2. Here in the deepest portion holes were started with the 6-inch casing, reducing to 4 inches, then to 2½, and even as low as 1⅝. Numerous boulders were encountered in this gorge which required blasting, and consequently the raising of the inner line of casing before blasting. This was sometimes accomplished by upward tapping of the casing, but often hydraulic jacks had to be used to raise the casing, to which steel clamps were fastened by bolts. When ledge rock was reached or when it was desired to drill a boulder, a Badger screw-feed Sullivan machine was set up over the casing and operated by steam from the boiler, a derrick being used to raise and lower the rods. This made a very handy combination, the whole outfit being readily moved from one hole to another. For this horses had to be employed, as the machine was not self-propelling. A very good selection of black diamonds was obtained, so that they wore exceedingly well. When weighed at the end of the work, surprising little diamond loss was shown. The rocks drilled were limestone, sandstone and shale. This machine put holes through 250 feet of drift, to a maximum depth of about 600 feet.

The Minnesota Rig. Sprague & Henwood, who did the bulk of the boring work in the Rondout valley, under various agreements with the board, introduced the "Minnesota" rig, a very simple and efficient machine for doing heavy surface work. This machine consists of a single-cylinder oscillating engine mounted on a heavy frame and operating a winch through heavy gearing and flywheel, the steam for the engine being furnished from a vertical boiler. A stout tripod was erected so as to rest partly on the frame of the oscillating engine, holding it down when heavy pulling had to be done. A powerful horizontal steam pump was operated from the boiler, furnishing wash water. Usually 5-inch,

PLATE 19.—Board of Water Supply steam drilling rig. Machine operated as a "Wash Rig" to reach rock and then furnished steam for Badger-Sullivan diamond drill, raised and lowered drill rods, etc.

3-inch and 2-inch casings are used, telescoping every 100 feet. The rope operating a hollow drive weight was operated from the winch, tapping the casing downward. When it was necessary to pull up for a shot, or for any other purpose, the casing was usually raised by upward tapping on the top coupling. Power for this tapping was furnished by a heavy flywheel. This is the particular virtue of this machine, as it was seldom necessary to use jacks for raising casings. When rock is reached, a small screw-feed machine is set up and operated by a belt from a pulley to the Minnesota rig, or else a hydraulic machine is set up over the casing. See Pls. 20 and 25.

Diamond Drill and Shot Holes in the Rondout Valley. Sprague & Henwood made a very good record in the Rondout Valley, never giving up a hole after it was once started. In one case the drill rods broke into a cave or heavy clay seam, and the rods snapped off just above the bit, which was never recovered although "fished" for a long time. Two 4½-inch shot-holes were put down near Shaft 4 to enable pumping experiments to be conducted to determine the porosity of sandstone and shales in this vicinity. A great deal of trouble was experienced in getting these holes down, as the rock was found to be seamy, and the shot frequently lost, and in one hole a mud seam was encountered which had to be cased, reducing the core to 2½ inches. The progress made in drilling these holes was one-fourth to one-fifth as much as made by diamond drills in this vicinity.

Churn Drills. At some portions of the work, particularly along the line of the Moodna Siphon, churn drills were used to penetrate glacial drift or rock. These were machines obtained by agreement with local well diggers. They do not give a rock core like the shot and diamond drills, the material coming to the surface in fine fragments. The machine consists of an apparatus for raising and lowering with a churning motion a string of tools attached to a rope. Only a small quantity of water is required to make a thick, creamy batter of the rock as it is broken up. From time to time the hole is baled out by a sand pump, consisting of an iron pipe with a valve in the bottom.

Churn Drills at Moodna Crossing. The string of tools consisted of a hardened steel chopping bit screwed into a stem from 10 to 40 feet long, and weighing upward to 3000 pounds. They were raised and lowered by a cable operated by a winch. These machines failed to penetrate the deep glacial drift in the Moodna Siphon, though they stayed weeks at a time on one hole, and holes were

Plate 20.—Sullivan Hydraulic Diamond Drill in New York City. Steam furnished by portable boiler and rods raised and lowered by tripod derricks operated from drum of drill.

abandoned with casing at various depths. Later on Sprague Henwood, under another agreement, installed Minnesota rigs, and succeeded in reaching bedrock with no great difficulty. Glacial drift along the line of the Moodna Siphon is of extraordinary thickness, the maximum, 350 feet, being the greatest depth of drift discovered along the line of the Aqueduct, with the exception of that overlying the Hudson gorge.

Shot Drills. The shot or calyx drill uses rods and core barrels similar to the diamond drill, except that the core barrel is generally larger in proportion to the size of the rod. It is fitted with a bit at the lower end, which is a heavy pipe with a single notch cut in it. Hardened steel shot is fed to this bit with the water, and the rock is cut by the grinding of the shot below the bit. An annular groove is cut and the core rises in the core barrel. At the top of the core barrel is a calyx extension and into this the chippings are collected, as the velocity of the wash water is usually not sufficient to carry the chips to the surface. When it is desired to bring the core to the surface, a few handfuls of coarse sand or gravel are poured into the rods and washed down. This grouts the core to the core barrel and it can be pulled up. Shot drills were used to only a limited extent in the Northern Aqueduct Department, as they were not able to work to good advantage due to the difficulties in getting holes through the difficult rocks there, but in the Southern Aqueduct Department they were able to do good work in the schists and gneisses of that region. They were also used to a considerable extent in New York on the City Aqueduct.

Because of the extensive use of boring machines of all kinds on the aqueduct work the engineers gradually came to learn that drilling demands the highest skill and patience of the men operating the machines and that it is poor economy to engage poorly equipped and inexperienced contractors to do this work.

Difficulties of Drilling. In addition to the troubles before enumerated, the following may be mentioned:*

In drilling surface material hard boulders are often encountered. A boulder in sand may offer great difficulties, the sand washing into the casing and making it hard to chop the boulder, or it may drop into a hole washed out under the casing. When the casing is raised to blast the boulder, the sand may rise in the casing, preventing the dynamite from reaching the boulder. Measurements

* See Robert Ridgway's Article, Proceedings Municipal Engineers, 1908, Subsurface Investigations of the Board of Water Supply.

should be carefully made to see whether it is low enough, or else the casing will be destroyed.

Great difficulty is experienced in deep holes in exploding the dynamite. This has been variously explained—by short-circuiting in the battery wires, by chilling of the explosive, or what is more likely, by the breaking of the exploder, by the pressure of the water, so that the spark is not properly formed when the magneto is discharged.

Various Difficulties Encountered in Sinking Casing, etc. Gravel is often difficult to penetrate, leading away the wash water and wedging the bit, separating it from the wash rods. The conical recovering tap is then let down on a line of rods, and cuts a thread on the end of the broken pipe, so that it can be raised. The same device is used when the diamond-drill rod is used to rotate the bit parts for some reason. Both inside and outside recovering taps are used. Sometimes the chopping bit·lies at such an angle as not to be recovered; in that case, it can be burnt up by repeated shots of dynamite, a very troublesome and tedious operation. Wash pipes are sometimes wedged in the casing by fine sand flowing between the two pipes. It has been found that a powerful pump is of great aid in preventing this, as it is in all other washing operations. Casings are often bent and parted by the severe usage given them in driving and pulling. It has been found that it pays to use extra heavy casing and heavy coupling. Even with heavy casings, they must be treated gently, as the power of almost any boring machine is sufficient to cause injury by heavy pounding or driving.

Drilling Rock with Diamonds. In drilling rock with diamond drills the machine must be carefully watched to see that an upward flow of water is always maintained, properly carrying away the cuttings and cooling the diamonds, also that the bit is fed carefully downward. If the first precaution is neglected the bit may run dry and the diamonds be lost through fusing of the steel. If a bit is used too long, the diamonds may become loose and fall out, or cores may become wedged in the hard rock, and cause the shattering of the inner diamonds. Sometimes a bit may be recovered when lost by reaming down to it with a larger bit and then raising it with recovering tap or electro-magnet.

On the City Aqueduct work, out of a total 17,687 feet of holes drilled, three bits were lost.

Breakage of Diamonds. In working through seams in hard rock, heavy diamond loss is sometimes experienced by the shattering

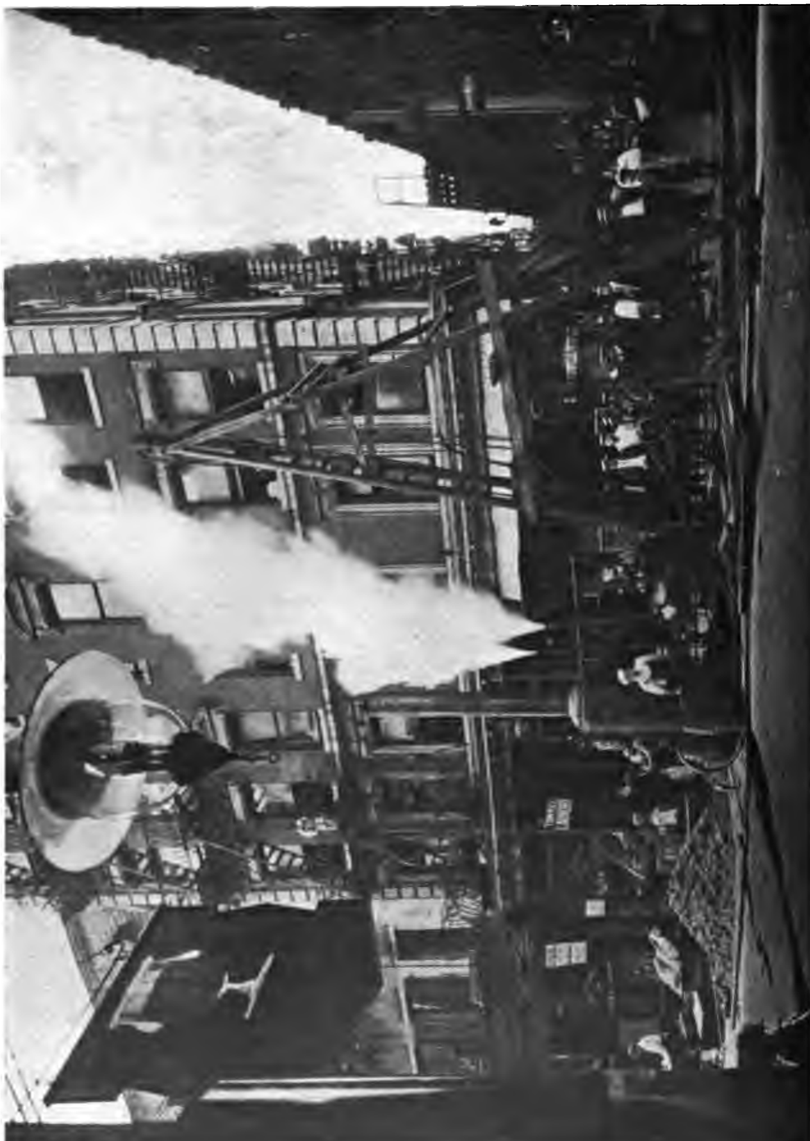


PLATE 21.—Minnesota Diamond Drilling Rig in New York City. Drilling in rock for core.

of the diamonds when the rods drop unexpectedly. The same thing may happen if, when pulling, the rods are allowed to slip back into the hole, crushing the diamonds.

Breakage of Diamond Drill Rods. If a diagonal seam is encountered, the rods are apt to be deflected so that the weight of the rods above the seam will break the rod at the seam, and the lower length will snap back out of line, so that it cannot be reached by the recovering tap. There is a slight chance of recovering it by an electromagnet.

Advantage of Diamond Drills. The diamond drill has the great advantage of working positively, a diamond bit being, without doubt, the most efficient rock-cutting tool known, and were it not for the high cost of diamonds would be extensively used for a great many purposes. As it is, its use is almost confined to exploratory work, such as that of the Board of Water Supply, to investigate foundations, mineral veins, etc. The diamond drill will work at any angle and will penetrate almost any rock, sound or seamy. In case rock is very bad, however, the hole may have to be reduced by casing, and the use of a smaller bit. The usual cores obtained by diamond drills are less than 2 inches in diameter. It is entirely practicable to drill larger holes, but the diamond loss becomes very high and the holes, consequently, very expensive. Also the bits used for obtaining large cores represent a heavy investment and the risk is rather large.

Limitations of the Shot Drill. Shot drills are of great use in drilling large holes; in fact, they can more readily obtain 4-inch cores than smaller sizes, and have been used to drill holes 15 inches or more in diameter for plunger elevators and for openings into mines. They seem to be most efficient in drilling in a uniform rock of medium hardness, but are very slow in drilling in seamy rock and very hard rock. Seamy rock with a strong flow of water will wash away the shot, leaving bare pipes to do the work alone. In very hard rock, such as the Shawangunk grit, it has been found that the shot drills are exceedingly slow and impracticable. For pure exploratory work where a small core is sufficient and where rapid progress is required to obtain needed information, the diamond drill is far and away more efficient than the shot drill and, due to its much faster progress, will generally drill more cheaply. It has been found that in some strata where the diamond drills could do 10 to 20 feet per eight-hour day, the shot drill could penetrate only 3 feet, the diamond drill, of course, furnishing less than 2-inch core, and the shot drill less than $4\frac{1}{2}$-inch. There is no doubt that the shot drill has its place and that it is an extremely valuable tool for obtaining large cores, and there are a great many places where large cores are desirable. The diamond drill, however, seems to be a perfected tool, while the shot drill is still capable of great improvement. As diamonds tend to be more and more expensive, the shot drill will tend to approach the diamond drill in efficiency.

Interpretation of Borings. After a boring is completed it then becomes necessary to interpret properly the samples and cores obtained, which can best be done by those who have witnessed the operation of the drill, as the various occurrences and methods of operations, the personnel and skill of the drillers all have a bearing. No better statement has been made than that of Mr. Ridgway:

Mr. Ridgway's Conclusions Concerning Borings. "To the engineer unused to such work it is difficult to judge whether a boring contract is being handled properly. The tendency is to magnify the difficulties encountered, when the trouble may lie with the contractor's methods or appliances. Months may be spent in gaining only a few feet at great labor, and anybody watching the operation might conclude that the difficulty was insurmountable. The substitution of a different machine or of men more efficient in this class of work means in nearly every case the successful completion of the boring. The experience of the drill runner is of course a very large factor in successful boring, but his experience alone cannot make up for inferior machines or equipment. Such troubles as the bending or breaking of the casing is frequently attributed to the difficult character of the ground, but the employment of heavy casing or proper machines will usually overcome the difficulty. The same considerations apply to boring in rock as in earth. A shot machine may be employed to do work for which it is entirely unsuited, or a small diamond drill, not of the hydraulic type, may be found inadequate for a certain rock.

"As stated above, misleading conclusions are apt to be made from boring work and records. Where a boring is having great trouble due to seams in the rock, one is apt to conclude that the rock itself is very hard, whereas such a conclusion may not follow at all. For instance a rock in which the strata are in a vertical position may be very difficult to bore with a diamond drill, but is in just the right position for tunneling through, as the layers will support themselves instead of caving in flat slabs, which might happen were the strata in horizontal position. Seams in rock will bother a rotary drill greatly, whereas a percussion machine may readily penetrate it.

"Reliance cannot always be placed upon the percentage of core recovered from different rocks. These percentages are apt to vary according to the variety of drill and manner in which the machine is handled. The dip of the strata is an important factor; slate on edge is very easily tunneled into, but may yield a very low percentage of core, whereas material difficult to tunnel may give a high percentage of core.

"It is most difficult properly to interpret wash-boring samples. If clay or uniform sand is being penetrated the samples are all right, but in a majority of materials only the coarser particles are likely to be preserved unless great care is used. Where hardpan, composed of a large percentage of clay, is being penetrated in drilling, it will cause the loss of most of the clay in the wash water, so that the little material recovered may be labeled 'Sand and Gravel' by the drillers, and an examination of the contents of the sample bottle will apparently bear out this erroneous conclusion."

CHAPTER V

EXPLORATIONS FOR HUDSON RIVER CROSSING

The Hudson River. That the Hudson is a barrier of considerable difficulty is shown by the fact that no bridge crosses the lower 75 miles of its course, there being only one in 150 miles. That it was at one time an active stream below Albany and not a tidal estuary is shown by its submarine gorge, which can plainly be traced for 120 miles south of New York to the continental border, beyond which the bottom drops abruptly from 600 feet in depth to 6000 feet, where there are remains of an old Hudson gorge at least 2800 feet deep.

Preglacial Gorges. In preglacial times the continental border was elevated so as to present a front about 3000 feet high to the sea; through this the Hudson cut deeply and the tributaries tended to cut back their valleys to the elevation of the Hudson bottom. But before this could be accomplished, subsidence occurred, and while the tributaries were in hanging valleys the whole was submerged to the extent of placing the Hudson valley far below sea level, the others at a little above. This was only brought out by the Board of Water Supply borings, the current theory among geologists being that the tributary streams, such as the Esopus, Rondout, Wallkill, Moodna, etc., having had a long time to work, had cut their valleys to the level of the Hudson for the lower portion of the course, and hence we would find at our aqueduct crossings buried gorges far below sea level. Much to the surprise of the geologists, no gorge much below sea level was found, even at the Moodna crossing 3 miles from the Hudson. But it took many borings to convince them of this, and it was only after there seemed no chance whatever of finding such gorges by borings that they gave up the search. Since then the shallowness of the gorges has been absolutely proven by the driving through solid rock of the Rondout, Wallkill and Moodna pressure tunnels below the streams. It would seem that the continent was elevated several thousand feet for a long enough period to allow the swiftly moving Hudson to cut a canyon rivaling the

Colorado, leaving the minor streams high up its sides in hanging valleys, with heavy cascades or falls at their mouths.

Borings in Buried Gorges. Between Albany and the sea no continuous line of borings to ledge rock had ever been drilled across the Hudson, and it was not known how far back the deep canyon at its mouth extended. Borings were made at the first proposed aqueduct crossing at New Hamburg, the lowest rock being found at elevation −223, but there remained a considerable gap between holes (1040 feet) when, because of the more economical location discovered west of the Hudson for the aqueduct, it was decided to cross below Newburgh, preferably at Storm King. Another line of borings had been made by the Pennsylvania Railroad through their tubes under the Hudson for the purpose of locating rock bottom for piles, but unfortunately there was also a gap here of about 300 feet, although most of the holes showed rock consistently at −300 feet. Even then there is doubt whether at this point the Hudson did not originally flow somewhat west of its present location.

Problem of the Hudson Crossing. The problem of the Hudson River crossing, as it confronted the engineers in 1906, can be stated as follows: A gorge had to be crossed with bedrock on an unknown elevation; that it might be very deep was indicated by the fact that near its mouth, 170 miles away, it was at least 2800 feet below sea level, and incomplete holes further upstream showed that it might still possess a great depth at Storm King. At this point the hydraulic gradient is 400 feet above the river surface, or nearly twice as high as the elevation of the span of the Poughkeepsie Bridge, the only one below Albany. The following possible methods of crossing the Hudson may be enumerated:

1. A bridge 150 feet or more above tide water to carry steel pipes.
2. Several steel or iron pipes laid in trenches dredged in the river bottom.
3. One or more shield tunnels driven by compressed air about 100 feet below river surface, steel lined or containing one or more steel or iron pipes.
4. A tunnel deep in sound rock.

Of these, the bridge was found to be the most expensive to construct and maintain, and the rock tunnel decidedly the cheapest, the most durable and satisfactory, so that it became necessary to make every effort to find a practicable location for it. At the same time, if rock could not be found under the river within striking distance, the second or third method could be availed of. Borings and geological studies were made of the river

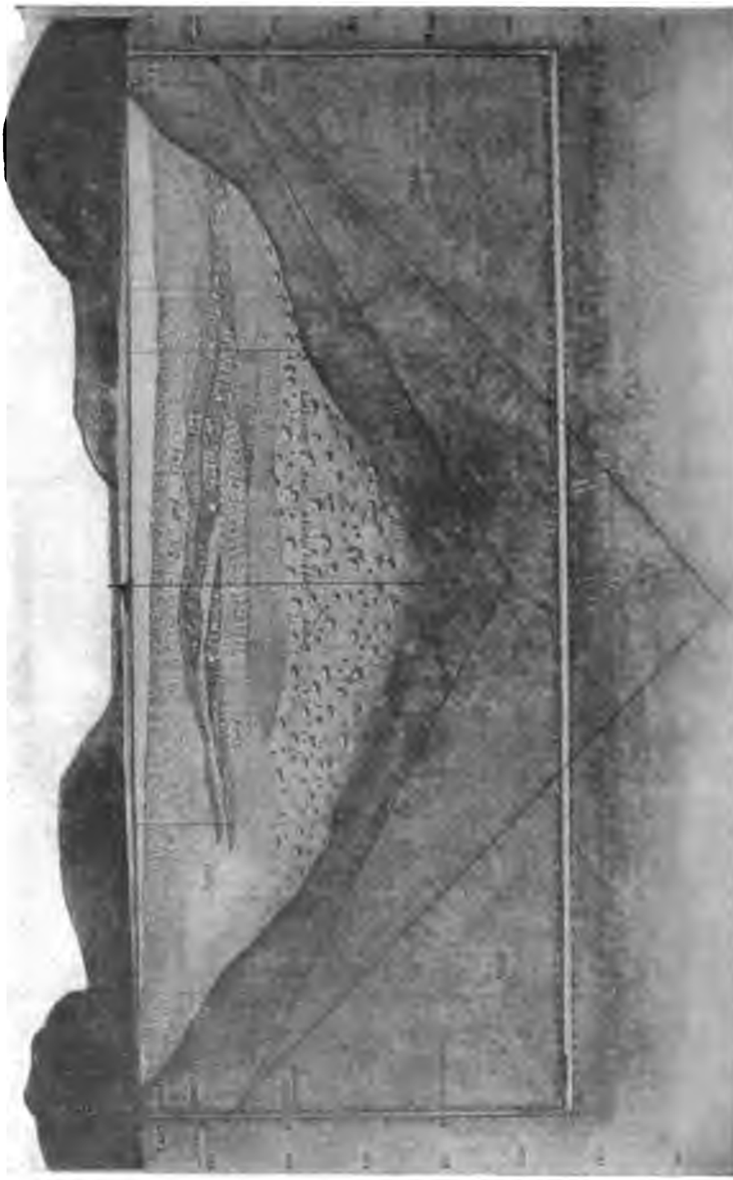


PLATE 22.—Pictorial Cross-section of Hudson River at Aqueduct Crossing between Storm King and Breakneck Mountains. Shows Position of Pressure Tunnel, Inclined and Vertical Borings and Materials Encountered in Borings and Tunnel.

from Peggs Point, 3 miles above New Hamburg, to Anthony's Nose in the Highlands, a distance of 21 miles. A narrow channel at the point of crossing was desirable, and geological conditions were an important factor. At Storm King and Little Stony Point granitic gneiss of a good quality was found on both sides of the river, with no indications of a change between. At the other crossings, limestone was found which it was desirable to avoid on account of its uncertain character. This favorable geological condition taken in connection with the narrowness of the river at Storm King and with the better location of the aqueduct leading to it on both sides of the river decided the crossing at this point. Therefore work was concentrated at Storm King. The explorations were made by the following methods:

1. Wash borings.
2. Core borings.
3. Test shafts on the shores of the river from chambers in which diamond-drill holes were put out under the river.

Wash Borings. At fourteen cross-sections of the river, lines of borings were made across the stream by means of wash drills operated from the deck of a large lighter. These gave only negative results, as the wash rods were stopped at from 100 to 300 feet by boulders and no attempt made to blast them through. Bedrock was later found to be several hundred feet lower.

Core Borings. These were made under contract with the American Diamond Rock Drill Company, and their assignees, the Phoenix Construction and Supply Company, of New York. The price paid by the city for vertical borings varied from $9.75 per foot to $50 per foot, depending on depth of hole. The equipment for drilling is described as follows by Messrs. Dodge and Hoke, Hudson River Crossings of Catskill Aqueduct, Proceedings of Municipal Engineers for 1910:

Equipment for River Borings. "The equipment which experience has shown to be best is a pile-driving scow 35'×100' with ways 60 feet high, a hoisting engine of 40 H.P. with two 7"×10" cylinders and two 12-inch drums, two 12"×7"×12" pumps with capacity for 100 gallons per minute each at 120 pounds pressure, and a 60 H.P. boiler, casing and wash pipe of 18-inch and 14-inch steel-welded pipe and 10-inch, 8-inch, 4-inch, 2½-inch and 2-inch, extra heavy wrought-iron drive pipe with screw joints and extra long sleeve couplings, a drilling machine, 1⅞-inch rods and enough diamonds for two bits. When the casing is surely seated in ledge and drilling under way the large scow and other equipment for wash boring can be dispensed with, the drilling machine being carried on on a platform clamped to the casing, and pump and boiler kept on a scow about 20′×30′.

"The scow is kept in position by at least six anchors at bow, stern and four corners. These must be from two to three tons each and have leads of 400 to 500 feet of ⅞-inch wire cable. The severe gales and rough water encountered at times make it hard to keep the scow exactly in position, while any movement, if it is toward the hole, is likely to bend the standing casing and destroy the borings.

General Method of Sinking Casing. "The general method of boring is to sink first a line of large casing as far as possible without too severe driving, then to put down the next smaller size inside of it, 'telescoping,' as it is called, and continue downward again, the telescoping of casing being repeated when necessary, until bed-rock is reached. A line of casing, of course, encounters skin friction against the drift material only below the bottom of the next larger casing, and in general an advance of 100 feet or more should be made with each size, though the first two sizes should be made considerably more than that in the fine material which lies on top. The importance of not having too much frictional resistance on a line of casing comes from the necessity not only of moving the line down, but of being able to draw it back, so that its end will be out of harm's way when blasting is done, hence care is taken against forcing when much resistance is felt. In the early work before the great depth of the gorge was known, and when the contractor knew less of how to do this kind of boring, the mistake was made of starting with too small casing and so coming down to the smallest size practicable while still a long way from rock; this made the last of the work on these holes excessively difficult and one of them had to be abandoned in an unfinished condition for this reason. The latest and deepest holes have been started with 18-inch casing; six reductions are then possible.

"The casing is lowered and raised by a wire cable fall passing over the sheave at the top of the pile falls to the drum of the hoister. As the casing goes down, it is added to in 20-foot lengths, the additional piece being supported by the fall while the men screw it into the coupling at the top of the line. Great care is taken with the joint, the coupling is extra long and an effort is made to have the pipe ends meet, so that in driving, the blows of the hammer will not be carried by the threads entirely.

Washing down Large Casing. "The first material encountered is mud and silt, and the large casing, being very heavy, goes

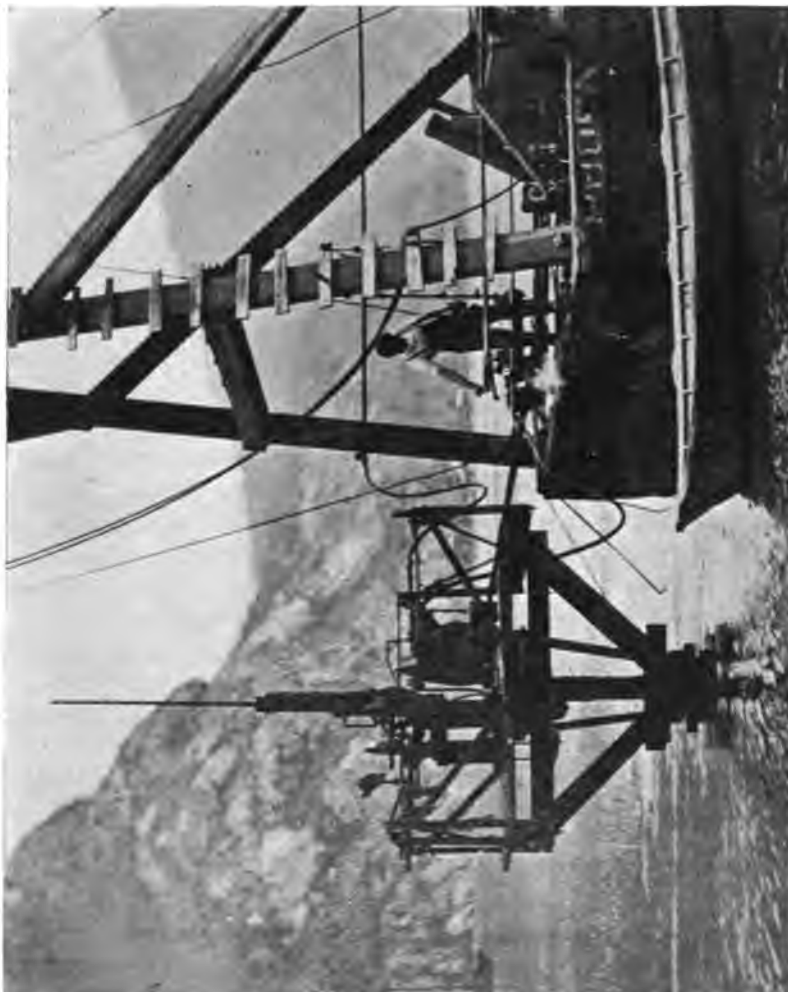


PLATE 23.—Diamond Drill Mounted on Casing of Bore Hole near Hudson Siphon and Attendant Scow.

into it for the first 50 feet very easily. When light driving ceases to have an effect, a 4-inch pipe is put down inside and connected with the pump by hose and a powerful stream of water forced through it, to stir up the material just below the bottom of the casing, the water returning inside the casing and bringing up the lighter material with it. The casing is at the same time pounded lightly by the piledriver hammer, which has a hole in its center through which the wash pipe passes.

"The position of the bottom of the wash pipe is a matter fo careful attention; it must be at or below the bottom of the casing to act upon the resisting material while, if it is too far below, the water of the jet escapes under the edge of the casing and no material is brought up. The position should vary with the material; in clay the wash pipe may go several feet below the casing without harm, while in gravel the water will escape in a few inches of space.

"In the large casings, the space between wash pipe and casing is so great that the returning wash water has little velocity and brings up only the finer material; the pebbles remain and must be taken out from time to time by a bailer. This consists of a 10-foot length of 8-inch or 6-inch pipe with foot-valve and a plunger, which can be operated from the surface; it is lowered to the bottom, the plunger churned up and down, and it brings up sometimes a large quantity of gravel and cobblestones. An 8-inch bailer will take in a 4-inch cobble. The bailer is an effectual way of removing material from large casing, but has the disadvantage, as compared with the wash pipe, that driving must stop while it is in use. With casing smaller than 6 inches the bailer cannot be used, but on the other hand, in a 6-inch or smaller casing, the space between the casing and wash pipe is small, and the returning wash water has enough velocity to be effective in removing the material.

Use of Wash Pipe and Chopping Bit. "When the casing is stopped by cobbles too large for the bailer or when the bailer cannot be used, a chopping bit having edges in the shape of a cross or X is put onto the bottom of the drill rods, and used as in churn drilling, the line of rods being repeatedly raised several feet by the hoister and dropped. The water jet is kept going at the same time, escaping through perforations at the end of the bit. This method is usually effective, if the stones are not too large, in breaking them up so that the wash water carries them off and the casing continues downward.

"The action of the chopping bit gives some indication of the nature of the obstacle; if it is a moderate-sized cobble, it breaks up after a time, chips from it wash up and the casing can be driven down; if a large stone is squarely in the way, the line of pipe rebounds upon hitting it and drilling into it is slow; if it is a nest of cobbles, chips come up freely, but the progress is slow and the casing usually does not go down at all.

Blasting below Casing. "In either of the latter cases, blasting is resorted to. The bit is removed and a line of 2½-inch or 4-inch pipe, with its lower end open, is washed down as far as possible into the hole made by the chopping bit in the sand and cobbles. The charge is put down in bundles of two or five sticks each, according as the 2½-inch or the 4-inch pipe is used, strung end for end on the exploding wire so that they will pass through the pipe; it is lowered by the wire, which is carefully measured off so as to surely reach the bottom. The pipe is then carefully lifted, leaving the charge among the cobbles or resting on the boulder as the case may be; the casing, if necessary, is also raised so as to be at least 10 feet above the dynamite. The charge is then set off by means of an electric battery and the casing immediately driven down again as far as possible.

"The dynamite most used is 60 per cent forcite, though in extreme cases a gelatin composed of 93 per cent nitroglycerine and 7 per cent guncotton has been used. A special exploder covered heavily with gutta-percha to bear the heavy water pressure has been used in the deep holes, as it has been found that a hydrostatic pressure of 500 feet will force in the plug of an ordinary exploder, breaking the fuse bridge and rendering it inoperative. A number of exploders are always used, located at different places in the charge, to insure its going off. The explosives are used very freely in difficult ground. A usual charge is from four to twenty sticks of forcite, and there is a record of one place where in advancing 1 foot eight shots and three failures of shots were made and 1 pound of forcite and 76 pounds of gelatine used, the charge which finally made an end of the obstacle being made up of 10 pounds of nitrogelatine. At times the shots fail to go off, either from the fault of the exploders, from leakage of the electric current or from chilling of the dynamite in the water, and the process has to be repeated."

Difficulties of Boring at Hudson Crossing. No work known to the writer requires a greater degree of patience, ingenuity and perseverance than boring through hard surface under the conditions prevailing at the Storm King crossing. In addition to swift tides and heavy river traffic, various governmental restrictions as to the space taken, etc., there is a short working season, entirely too short to put down a 700-foot hole. This made it necessary to disconnect at the river bottom and cap the hole, recovering it if possible in the spring. Long lines of casing, however strong, are damaged by the heavy pounding and pulling necessary, bent by boulders and shattered by blasting, necessitating frequent pulling of wash rods and casing. In four years of drilling only six holes reached river bottom. When at last one hole was supposed to have reached bottom at the depth of about 600 feet, a river steamer which had broken a propellor drifted on the boring rig, bending the casing when only a few feet of core had been pulled. The difficulties of the boring came to be associated with the entire work and people began to believe the river bottomless, and vague accounts were circulated of a great fault in the bottom and "rifts" in the rock, etc.

Time Taken to Sink to Rock. If the driving and telescoping of a casing could have been continuous, a depth of 1000 feet would have been reached in a few months, by slow and steady downward progress, but the frequent pulling of the casing preparatory to blasting heavy boulders was a tremendous consumer of time and patience. Often, also, the wash pipe was stuck by inflowing sand and gravel grouting itself to the casing for several feet, and to free the pipe it became necessary to pull the whole line of casing. This also occurred at times so that it became necessary to pull the inner casing. Inflowing sand also lowers the efficiency of the chopping bit by forming a cushion between it and the boulders, or floats up the dynamite to a point above the boulder where it is not effective, or where it may even split or damage the casing.

Breakage of Wash Pipes and Casing. Often the wash pipes broke apart, and then many days were spent fishing for the lower piece by means of conical recovering taps. Chopping bits were twisted off and had to be washed to one side or shot or "burned" up by dynamite, but before this was accomplished the bit or piece of pipe might have followed down the casing for a long way, only yielding to repeated shots. One of the worst mishaps is to have the casing get "pinched" between two boulders, crumpling it up or bending it to one side, if one boulder is the agent. The hole might then as well be abandoned, as shown by one instance where after a depth of 588 feet had been reached, a bent casing at the bottom was cut off above the bend by means of a rotary cutter which could be expanded against the pipe at any desired depth. Five weeks' time and much dynamite was consumed in trying to force a bent casing to one side, but without success. A special tool was used called a "gouge," which is a solid core designed to force out the crumpled sides of a casing to allow a smaller one to pass through. Some holes were lost by the casing above the bottom being bent by the scows overriding them in a storm, or even by toppling over by their own weight. Later guard scows were used and the tugboats kept away at a safe distance.

Drilling after Rock Bottom is Reached. When rock or what purported to be rock was reached a platform was constructed by driving piles upon which the diamond drill operated, or what was found to be much preferable, wooden platforms were clamped to the casing braced by taut anchor lines, attached near the surface of river. The platform was just large enough to support the drill and afford working room for a few men, the auxiliary machines being carried on a scow which contained derricks for raising and lowering rods, etc. The drilling in rock from the platforms is about as previously described. Large hydraulic-feed diamond drills of 1000 feet capacity were used, giving $1\frac{1}{2}$-inch core from bit $2\frac{1}{16}$ inches in diameter. The bit contained eight diamonds, four in each row, mounted in 10-foot core barrels rotated by rods $1\frac{7}{8}$ inch diameter with interior hole $1\frac{1}{2}$ inches; at joints, only $\frac{3}{8}$ inch. Only six holes progressed far enough to furnish core from the solid river bottom.

Hole No. 24, the deepest, finally reached the depth of 768 feet after fifteen months of work, but without reaching bottom. By this time all desired information was obtained by other and better means.

Force Employed in Borings, and Progress Made. The following is taken from paper by Messrs. Dodge and Hoke, "Municipal Engineers," 1910.

"The force on each scow consists of a foreman and three or four men; this foreman is also a runner when it comes to diamond-drill work. There is also a general superintendent. Wash boring can be done only by daylight, so, in general, there is but one shift per day; on diamond-drill work it is usual to work two shift daily.

"Of fifteen river holes, six reached rock it is believed; of the other nine, two were knocked over by passing vessels, one by its own scow, one fell over of its own weight, two were abandoned because of conditions at their bottoms, two were discontinued because supplanted in usefulness by other holes, and one is still in progress. Figures of average progress are not of great value, as of course in the shallower holes speed was much greater and in the deep holes less. In the progress on diamond drilling the time used in setting the platform and other preparation is included and, as in several cases the distance drilled was small, this affected the result largely."

Number of borings	15
Aggregate length in water	767 feet
" " earth	4656 "
" " bedrock	202 "
Average progress per shift in earth	2.3 feet
" " bedrock	2.2 "
" " water, earth, and bedrock	2.7 "
" " earth in boring No. 24, 749 feet deep	1.6 "
Average progress per shift in earth and water boring No. 24, 749 feet deep	1.8 "

Uncertainty of Vertical Bore Holes in the Hudson. It was early realized that vertical holes would furnish only inconclusive evidence as to the rock condition under the Hudson River, for the reason that there would always remain a doubt as to whether there might not exist, between the holes which could be put down, a more or less narrow vertical zone of decayed, fissured, or faulted rock. In addition, the drilling of the vertical holes in the Hudson proved to be so slow that there was grave doubt whether enough of them could be put down in time to give even a fair estimate of the depth of sound rock underlying the river.

In the Harlem River siphon of the New Croton Aqueduct, vertical borings failed to reveal the presence of a water-bearing seam between the gneiss and limestone discovered in the first test tunnel driven at an elevation of −150, and afterwards explored by inclined diamond-drill holes from this tunnel. To get below this seam, the shaft was deepened 150 feet and the tunnel put through safely at elevation −300.

The very first contract provided that inclined holes would be required. One such hole was drilled on each bank, but it was seen that owing to the contour of the river bottom these holes would cross at prohibitive depths.

Agreement 37 for East and West Test Shafts, etc. To facilitate the exploration of the Hudson crossing, and to make a start on the construction of the Hudson Siphon, Agreement 37 was advertised early in 1907, providing for the sinking of a shaft at each bank of the Hudson and the drilling of inclined diamond-drill holes from chambers in their sides. These holes were to be long enough to overlap under the river and to determine with certainty the continuity of rock below the river. The work was let to the Cranford Company, which started the excavation of the West test shaft on March 7, and the East shaft on April 6, 1907. These shafts were so located as to afterward become the uptake and downtake shafts, respectively, of the Hudson Siphon. Under this agreement, the guaranteed progress was to be as follows:

$4\frac{1}{2}$ feet of rectangular and 4 feet of circular shaft per day, including timbering of 10″×10″ timbers, forming 9′ 8″×9′ 10″ cage-way in the circular and 9′ 8″×16′ 4″ in the rectangular shaft. To do this work the Cranford Company assembled at the East shaft two 125-H.P. boilers and two Sullivan straight-line, 2-stage air compressors with a capacity each of 1160 cubic feet of free air per minute. At the West shaft only one compressor was installed. Both shafts were served by stiff-leg derricks, and Sullivan drills were used.

Suspension of Work by Contractor. Although strenuous efforts were made to keep up with contract requirements, the contractor soon found himself falling behind. The work was suspended in December, 1907, because, as the contractor stated, the city was behind in its payments. Instead of the guaranteed progress the following was made :

Rectangular........	18 ft. by 11 ft. 4 in. 2.24 ft. per 24-hour day
Circular...........	17 ft. 8 in. in diameter, 1.92 ft. per 24-hour day
Circular...........	16 ft. 10 in. in diameter, 1.25 ft. per 24-hour day

For elapsed time, the West shaft had an average progress of 30 feet per calendar month and the East shaft 35 feet per month.

Continuation of Work by City. Later, it was decided to continue the work of excavating the shafts by day labor under the supervision of the Board's engineers. The plant of the Cranford Company was considered inadequate for sinking the great depth that the shafts were to go. The derricks were removed, the tops of the shafts concreted and head frames erected. These head frames were built so as to accommodate suitable cages for the tunnel driving. J. S. Mundy 16″×20″ double-cylinder single-drum hoists were procured. On the east side steam was supplied by two 100-H.P. Ames boilers, and at the west side the old compressor-plant boilers were moved to the shafts to give power to the engine. The compressor plant at the east side was enlarged by two 150-H.P. Erie boilers and by the Sullivan straight line compressor from the west side of the river. At the West shaft a compressor plant was rented from the Ingersoll-Rand Company. This plant was erected by the company with the understanding that after a certain amount had been paid by the city in monthly installments, it would then revert to the city. This plant consisted of three Babcock & Wilcox 130-H.P. water-tube boilers and two

16″×28″×25¼″×16½″×16″ Ingersoll-Rand type HH^3, cross-compound air compressors, each having capacity of 1392 cubic feet of free air per minute. It was conveniently located to receive coal from the West Shore R.R., the air being delivered through 2500 feet of 6-inch pipe to the West shaft. Sullivan UH 3⅝-inch drills on tripods were retained in use at the East shaft, while a combination of Ingersoll-Rand 3¼ inch and Sullivan UF 2–3¼-inch drills on shaft bars were used on the west side. After the shafts were unwatered, drill chambers were excavated about elevation −250. From these it was planned later to drive diamond-drill holes beneath the river. The chambers were sufficiently large to allow the pulling of rods of 30 feet lengths from holes drilled from 20 to 45 degrees below the horizontal.

Sinking of East and West Test Shafts by City. Under Division Engineer Wm. E. Swift, Superintendents Roy and Harrison were placed in charge of the East and West shafts respectively, and they were supplied with a force of men obtained through the Municipal Civil Service Commission. These men had to be taken in rotation from the list and were only in part skilled shaft sinkers. The supplies and materials were obtained on requisition in the usual way. Competitive bids had to be obtained for most of the supplies and machinery, this proving to be a much slower and more cumbersome method than that employed by contractors. Nevertheless, by January 1, 1911, both shafts were sunk to a depth −1100 feet and headings driven part way under the river. It had been established by two pairs of inclined diamond-drill holes, to be described later, that this was sufficiently low for a safe crossing for the tunnel beneath the river. In addition to the diamond-drill chambers, pump chambers were excavated at about −400 and −800, capable of holding three 16″×7″×18″ Jeansville duplex plunger pumps. Later these chambers were supplied with pumps of the above type sufficient to handle the existing flow.

Timbering of Shafts. The shafts were timbered with 8″×8″ yellow pine timber sets with a clear way of 9′ 8″×9′10″ placed on 5½ feet centers and lagged between with 2-inch pine plank. From 50 to 100 feet of shaft were timbered at a time, as the character of the rock permitted. The timbers were supported and built up from 10″×12″ white oak bearing timbers which rested in niches cut in the shaft walls. From time to time concrete rings were placed behind the lagging to intercept dripping water, which was lifted by small ring pumps to the nearest chamber above. Upon the construction of the pump chambers all the rings above were piped to them.

Ventilation and Pumping at Shafts. Ordinarily shafts are not artificially ventilated except by compressed air released by drills and opening of air pipes at the manifold after blasting. However, at the East shaft a "smokejack" 1′8″×4′ was constructed of 2-inch tongue-and-groove boards in one corner of the shaft. A strong upward current of air was caused to circulate in this by exhausting the pump operated on part steam and part air. At the West shaft the same function was performed by a 30-inch fan exhausting through a 12-inch spiral riveted pipe. It was anticipated that as the shafts were sunk very close to the water's edge a strong inflow of water might be obtained. Nevertheless they proved to be remarkably dry. At depth of 250 feet only 5 gallons per minute was yielded by the East shaft, and by the West shaft, 12 gallons. At the full depth of the shafts, 1100 feet, they made only 150 gallons in the East shaft and 30 gallons in the West shaft. At a depth of −367′ a water-bearing seam was struck in the East shaft which threatened to be very wet and finally yielded only 20 gallons per minute. Strange to say, a small diamond-drill hole driven beneath the river gave more water than the total shaft, yielding at one time 180 gallons per minute when open.

"Popping" Rock in Shafts. The rock in general encountered in the shafts was firm and hard, except that near the bottom of the West shaft "popping" rock was struck. The rock here seemed to be under great stress, so that when the surface of the rock was exposed to the air in the shaft, small flaky wedge-shaped pieces snapped off with a popping noise. This is a common phenomenon where rocks are under great compression, and particularly noted in mines and even in quarries. Geologists classify the rock as granitic gneiss with diorite veins. The "popping" rock was made safe by using steel plate lagging supported by circular steel ribs and packed with broken rock. The progress made under the City, based on elapsed time, averaged 39 feet in the East shaft and 40 feet in the West shaft, the maximum monthly progress in the East shaft being 65 feet and 69 in the West. It was decided, when the shafts were down, that driving the tunnel and the lining of it and the shafts would be done by contract.

Agreement No. 74 for Inclined Holes. As soon as the diamond-drill chambers were excavated Agreement No. 74 was let to bore inclined holes from them. This agreement was drawn up in the light of the experience obtained by boring similar holes in the mines of Lake Superior, which had previously been visited by Senior Designing Engineer Wiggin. The experience from this region is that the holes usually turn upward, so that the bit tends to gain a higher elevation than the first pointing of the rod would indicate. The holes were to be so placed as to pass at elevation −1200 and the agreement was so drawn as to pay the contractor (Sprague & Henwood) a higher price in case they terminated within a certain prescribed zone. The two items of the bid were as follows:

Item No. 1. For drilling the first 900 feet of any hole or for drilling the remainder beyond 900 feet of any hole not included in item No. 2, the sum of $6.50 per lineal foot.

Item No. 2. For drilling the remainder beyond 900 feet of any hole which either terminates within the ordered zone or passes in solid rock about the ordered zone a hole from the opposite side of the river, the sum of $10 per lineal foot.

Inclined Hole for East Shaft, 1/A-74. The first hole No. 1/A-74 was started June 1, 1909. A Sullivan B drill (see Pl. 24) rated for 3000 feet of hole was set at an angle of 43 degrees below the horizontal, the slope of the tangent to the prescribed zone above mentioned. It was expected that due to the sagging of the drill rods in the hole the bit would turn upward so as to traverse the zone, the great fear being that it would turn up too much, so that the bit, core barrel and 60 feet of rod immediately following were all of the same size, actually $2\frac{11}{16}$ inch in diameter. Behind these guide rods ordinary 2-inch rods were coupled on as the hole lengthened. A $2\frac{1}{2}$-inch bit set with 8 diamonds were set to only $\frac{1}{64}$-inch clearance. Contrary to expectation, the hole turned downward. At a depth of 177 feet the guide rods were taken off and ordinary 2-inch rods used, the expectation being that the sagging of these rods would force the bit upward. At 280 feet, however, the rods were adhering to a straight line, and so continued to a depth of 641 feet. Here a 2-inch bit was substituted. A tapered core barrel was also used and the hole took an upward turn at an angle of 37° 20′. At 1398 feet the hole turned downward again and continued so until the end.

Occurrences in Drilling Hole from East Shaft. Hole No. 1/A-74 encountered water at a small depth. This gradually increased in amount until at a depth of 734 feet the flow was 90 gallons per minute, and was hampering the work. At this point the hole was nearly lost as a result of the back pressure exerted by the water, the pump failing to keep the flow through the hollow drill rods. The bit heated and was burned fast to the rock. The rods were withdrawn, leaving the bit in, which, however, was subsequently recovered by reaming a $2\frac{1}{2}$-inch hole and removing it as core with the steel

PLATE 24.—Hydraulic Diamond Drill at Work in Chamber of Test Shaft, Hudson River Siphon.

and diamonds fused into the rock. The water was then shut off by casing the hole with 2½-inch flush-joint pipes at the end of which diamonds were set. The whole pipe was turned by the machine until the end containing the diamonds fused into the rock, as in the case above described. This reduced the flow of water to 5 gallons per minute, but at a depth of 1085 feet the hole again was making 180 gallons per minute, sending a solid stream of water 10 feet from the mouth of the hole, when the rods were withdrawn. This made drilling very disagreeable, and the pressure was strong enough to push the rods into the drill chamber without the aid of the hoist. At a depth of 1234 feet it was again cased with 2-inch flush-joint casing, and the hole drilled to its final depth, the flow at the end being only 70 gallons per minute, which was judged to be the maximum flow this long hole would give under full head.

Loss of Diamond Bit. At a depth of 1834 feet the bit, valued at $1500, was again burned fast and never recovered, although two months were spent trying to recover it and 600 feet of rods. This hole, although it did not quite reach the center of the river, together with that from the west side furnished valuable information.

Inclined Hole from West Shaft. The hole started from the West shaft at an angle of 38° was much more successful and met with little difficulty. This hole never had to be cased. The flow of water was never greater than 5 gallons per minute. This hole also tended to point downward rather than upward, as desired. It was, however, drilled a distance of 2051 feet, so that its end overlapped the first hole, although 80 feet below it (see Pl. 22). With the completion of this hole, No. 2/A-74, indisputable proofs were at hand that the crossing of the Hudson River by a deep tunnel was entirely practicable, as the cores of both holes were almost continuous, showing the presence of no fault or poor rock. Together these two holes showed that the river bottom did not extend below the depth of −1450 and that the lowest rock in the river bottom might be considerably higher.

Agreement No. 77 for Two More Inclined Holes. A new agreement No. 77 was prepared, Sprague & Henwood again being the successful bidder. This required the drilling of a pair of holes to cross at about elevation −900 feet. These two holes were drilled to a length of 1651 feet, crossing at elevation −955 feet. No attempt was made to curve these holes upward, and although the bits were set for small clearances, the slope of the holes tended to increase. No particular difficulty was experienced in drilling these holes, the core obtained showing continuous and sound granite. These holes are supposed to skirt the bed-rock profile in the river, but luckily they did not intersect it at any point. The only unfavorable indication from the hole was that wet ground might be expected in the neighborhood of the East shaft, but it was thought that the water must come from narrow seams or joints in the rock rather than from areas of bad or broken ground. The following detailed records of these holes is given in table prepared by Messrs. Dodge & Hoke:

TABULATED HISTORY OF INCLINED BORINGS ACROSS THE HUDSON CHANNEL

	First Set.		Second Set.	
	Hole No. 1/A-74. East.	Hole No. 2/A-74. West.	Hole No. 1/A-77. East.	Hole No. 2. A-77. West.
Work started	May 24,'09	July 20,'09	Mar. 29,'10	
Drilling begun	June 1, '09	July 29 '09	Apr. 5, '10	Apr. 20, '10
Drilling finished	Dec. 15, '09	Mar. 31,'10	Aug. 4, '10	Aug. 25,'10
Elapsed time of drilling, days	198	214	122	127
Working time, days of three 8-hr. shifts	167	192	85	107
Actual drilling time, 8-hr. shifts	331	429	214	279
Feet drilled per actual drilling shift	5.54	4.78	7.72	5.92
Feet of 4-in. hole and percentage 3-in. core recovered	7.2—47%	8.0—75%	8.5—78%	7.1—76%
Feet of 2¾-in. hole and percentage 2-in. core recovered	633.8—79%	711.3—91%	715.5—84%	772.4—83%
Feet of 2 1/16-in. hole and percentage 1⅜ in. core recovered	593.0—41%	759.5—76%	927.4—48%	872.6—68%
Feet of 1 7/16-in. hole and percentage 13/16-in. core recovered	600—27%	572.8—22%		
Total depth of hole	1834	2051.6	1651.4	1652.1
Total core recovered and percentage of depth drilled	1013.2—55%	1360.3—66%	1052.1—64%	1245.0—75%
Elevation of top of hole	−281.0	−251.2	−279.7	−245.8
Elevation of bottom of hole	−1482	−1564	−965	−961
Inclination below horiz. at top	43°	38°	22° 53′	23° 40′
Inclination below horiz. at bottom	38° 55′	44° 47′	23° 35′	25° 55′
Max. variation of inclination	7° 15′	7° 20′	2° 52′	2° 27′
Max. water flow from open hole	180 gals./m	5	120	25
2½-in. flush joint casing used, feet	735	none	724	723
2-in. flush joint casing used, feet	499	none	none	none

Great credit must be given to Sprague & Henwood for their skill and persistence in drilling these four holes under the Hudson River, which must be considered the most difficult drilling work on the whole line of the aqueduct.

Method of Obtaining Inclination of Drill Hole. To obtain the inclination of the holes hydrofluoric acid was used to etch glass tubes inserted at various depths. An ordinary vial $\frac{7}{8}$ inch outside diameter about 5 inches long containing a solution of 9 parts of water and 1 part of hydrofluoric acid is placed in a water-tight steel shell about 1 foot long, which has the same outer diameter as the rods and is bored to exactly hold the bottle. The shell or tester is coupled to the rods and lowered to the required depth. During the time of lowering the rods no definite line is etched, because the rods in turning supply the acid to all sides of the tubes and the solution is too weak to act during this interval. At the required depth the rods are clamped and allowed to rest long enough to etch a line on the tube. At great depths this period may be as long as one hour. When withdrawn, it is found that the acid has etched an approximately horizontal line on the tube, and this operation is repeated for various depths. To obtain the angle of the etched lines with the axis of the glass tube, a protractor is used. Owing to the effect of capillary attraction on the acid, the observed angle is not the true angle and various corrections have to be made. These corrections are found by clamping tubes at various angles and observing the angle of the etched line to the horizontal. A minus correction, varying from 4° for a reading of 26° to 8° for a reading of 52°, had to be applied to obtain the true slope. Tests were made in the holes at depths not more than 100 feet apart.

Pressure Gauge and Hydrofluoric Acid Test for Obtaining Inclination of Holes. The hydrofluoric acid test had the objection that one erroneous reading would change the position of all the holes below it. An effort was made to obtain an independent check on the acid test by the use of a pressure gauge. This gauge was designed by Dr. Kalmus and Mr. Lewis of the Massachusetts Institute of Technology, and consisted of a flat steel tube so arranged that when under water, it would force a column of mercury to varying heights, depending on the pressure. This instrument was calibrated so as to read correctly various depths of water. It was found, however, that when lowered in the hole, no matter how carefully, various impact pressures were produced, which ran the readings up higher than they should have been, so that unfortunately no reliable readings were obtained. It is probable that the hydrofluoric acid tests give fairly good, reliable results, but by this means the depth of the holes and not the direction was determined. As yet no reliable apparatus has been invented for determining the horizontal direction of drills, though an instrument has been devised by which a compass needle is allowed to rotate in liquid paraffine at prescribed depths, the paraffine being melted by an electric current. When the current is turned off, the paraffine hardens, and the needle is recovered when the rods are withdrawn in the position it occupied at a known depth. This probably can give but a rough determination at best.

Final Determination by Borings at Hudson Crossing. The four inclined holes gave definite enough information to enable the engineers to fix the crossing for the tunnel at elevation −1100, which ought to give at least 200 feet of sound rock at the lowest point of the gorge.

The uncertainty for a long period as to the depth of rock bottom of the Hudson River, and the agitation conducted by certain newspapers against the whole project, created the impression among a number of people that there was something particularly difficult or insurmountable about the Catskill Aqueduct project and an effort was made to postpone the letting of any contracts until the exact status of the Hudson crossing could be determined. Had this been done four valuable years would have been lost and the cost of the whole project greatly increased through interest charges, to say nothing of the tremendous loss which would be entailed should a water famine caused by insufficiency of the Croton water supply overtake the city, such as was narrowly escaped in 1911. The engineers of the Board, and particularly those in direct charge in the field always had implicit faith that the Storm King crossing was entirely feasible. As a matter of fact, the difficulties overcome in constructing the Rondout siphon, were, in the opinion of Department Engineer Ridgway, far greater than those encountered at the Hudson River crossing.

CHAPTER VI

THE ASHOKAN DAMS AND RESERVOIRS

Contract 3

Ashokan Reservoir. The principal contract of the Catskill water works, Contact 3, was advertised early in 1907. This contract and several smaller ones provide the work necessary to form the great Ashokan reservoir, see Pl. 25. Under it the Esopus and the Beaverkill are dammed, the former by the great Olive Bridge dam, containing the heavy masonry section, the latter by various dikes. A dividing weir and dike, joining the Beaverkill dikes to Green Hill, form an East and West basin with flow lines at elevation 587 and 590 above sea-level. The surface water from the West basin discharges over the dividing weir into the East basin, whence excess flood water is disposed over the Waste Weir, which discharges into a small brook flowing into the Esopus, over three miles below Olive Bridge dam. This spillway is a small masonry overflow weir founded on rock, and the waste channel is a concrete apron formed on it. The overflow channel being large, there is absolutely no danger to the main structures to be apprehended from flood.

Water from Schoharie and Catskill creeks may be stored economically in the Ashokan reservoir. The water from Schoharie Creek can be delivered into Esopus Creek some miles above the reservoir by a tunnel ten miles long through the Catskills; the Schoharie in turn is to be dammed near Prattsville, and the water from the reservoir there formed to be directed into the tunnel. In addition, Catskill Creek water can be delivered into the easterly end of the Ashokan reservoir by a small branch aqueduct about thirty-two miles long.

Source of Catskill Aqueduct. It was originally intended to place the connection with the aqueduct at the east end of the East basin near West Hurley, but the swampy character of the ground in this basin made it undesirable to lead all the water from the Esopus through it. A deep channel, longer than the combined lengths of the two channels to be constructed, would also have been required to draw the lowest water from the West basin. In addition, a shorter and much less expensive location of the aqueduct was obtained from a point near Olive Bridge. The outlet was finally located at Brown's Station, where a dividing weir could be constructed at a small cost. The supply, therefore, can at any time be drawn exclusively from either basin, or from both basins at once. Here, consequently, are located the gate houses for controlling the draft from the reservoir, and also means for aerating the water.

Soil Stripping. The advisability of stripping the soil from the bottom and sides of the reservoir to prevent decomposition of organic matter and the resulting odors and taste was considered by Consulting Experts Hazen and Fuller. It was finally concluded, however, that stripping would not insure permanent relief from these troubles, and that the money could be expended more advantageously for aeration and filtration.

Award of Contract 3. On August 31, 1907, the Board of Water Supply decided to award Contract 3 to MacArthur Bros. Co., and Winston & Co., this despite the fact that their total $12,669,775 was over $2,350,000 more than that of the lowest bidder, John Peirce & Co., the other three bidders ranging around $14,000,000 and over. This gave an opening for opponents of the whole project to raise a cry of favoritism which reached such proportions that Mayor McClellan ordered an investigation by the Commissioner of Accounts of the award of this contract. This brought out the fact that MacArthur's bid was close to that of the engineer's estimate, while Peirce's bid plainly showed the inexperience of his bidders.

Controversy over Contract. It did not seem fair to the city to risk letting this job to an inexperienced and erratic bidder. It was difficult to explain to the public that the low bidder, though bonded to the amount of $1,000,000, could not be trusted with this work. It is very difficult to forfeit a bond of a contractor who fails to keep up with his schedule, previous experience being that he is always able to raise a legal question or to turn over the work to receivers with whom it is even harder to deal than with the original contractor. Mistakes in management at the outset of the work, or inadequate plant, are very hard to remedy and, even granting that the first contractor can be gotten rid of, it causes great loss of time and increased expenditure to start over again with another one. The principle of awarding contracts to a bidder, not the lowest, on the ground that his figures are reasonable and his equipment and experience suitable for the work was well worth

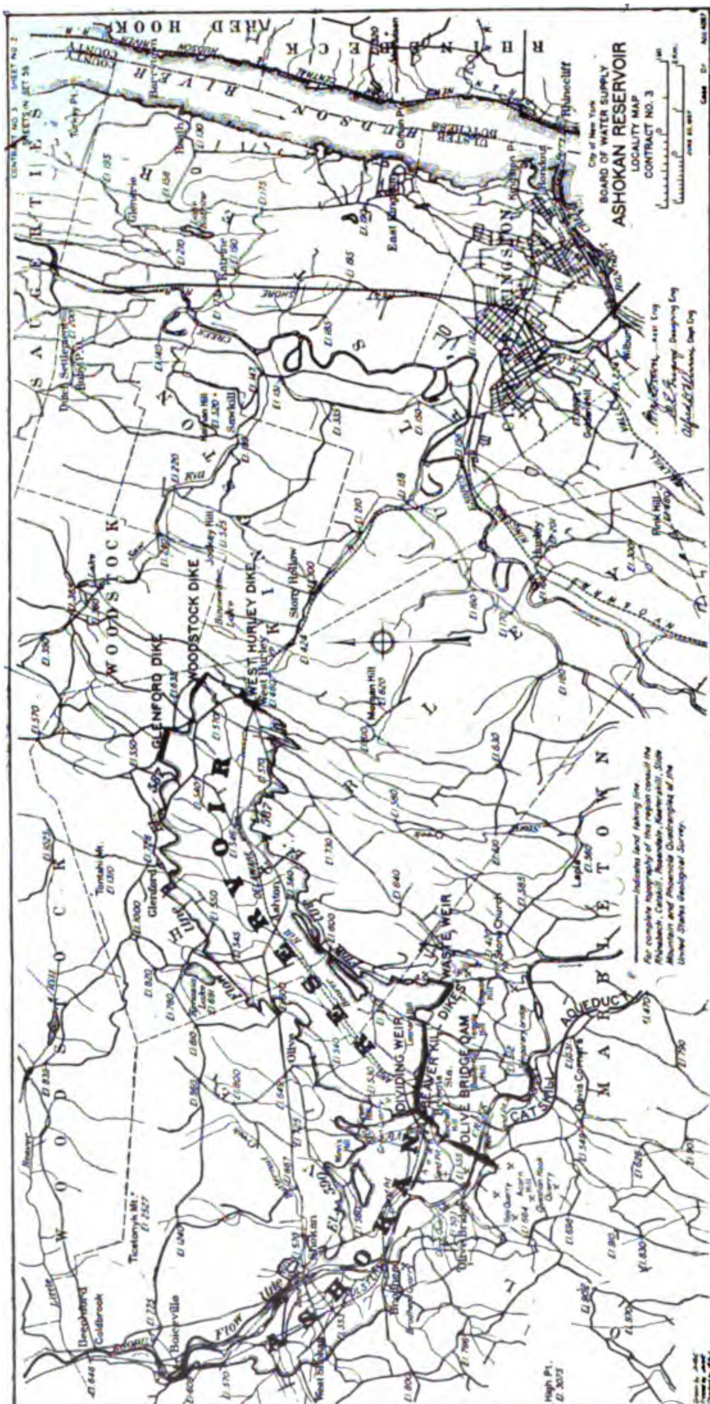


Plate 25.—Map of Ashokan Reservoir and Surrounding Country, Showing Location of Olive Bridge Dam, Dividing Weir, Beaver Kill Dikes, Waste Weir, and Dikes near West Hurley. Also upper portion of Catskill Aqueduct.

fighting for, as shown by the history of this and other contracts on the aqueduct.

The progress made so far on Contract 3 has been satisfactory, so that nobody would now question the wisdom of the board's award. John Peirce & Co., a short time after this controversy, failed and went into the hands of receivers.

Work under Contract 3. Under this contract a reservoir of 127,000 million gallons will be created by the construction of the Olive Bridge dam, Beaverkili dikes, Waste Weir and Dividing Weir, together with the gate chamber, inlet channels, pressure aqueducts, etc., shown on plan. The total length of dams will be about four miles. Ultimately highways will traverse the tops of the dams, the West and Middle dikes and the Dividing Weir, and highways will also encircle the reservoir; but these are to be constructed on other contracts, as are also some dikes 1.6 miles long closing gaps at West Hurley.

Under this contract the preliminary estimate gives 2,480,000 cubic yards excavation in all classes; 425,000 cubic yards of rock excavation, and 7,500,000 cubic yards of embanking and refilling. The masonry of all classes totals 882,000 cubic yards, for which over 1,000,000 barrels of cement will be required. The approximate quantities and the successful bid are shown in table on page 118.

Olive Bridge Dam. Although the dams of Contract 3 extend for a distance of four miles, only a portion of the Olive Bridge dam. 1000 feet; the Dividing Weir, 1100 feet long; and the Waste Weir, about 1000 feet long, are to be of solid masonry, the remaining structures being concrete core walls surrounded by rolled embankments. The Olive Bridge dam was designed in the light of the experience obtained in others of its class, and has several original features. On similar dams it was found that contraction cracks occur, causing unsightly leaks on their downstream faces, this occurring even where reinforced by steel. It was, therefore, decided to divide the dam above a certain elevation into sections by transverse expansion joints, the interval between joints being well within the distance at which the occurrence of cracks had been observed. This interval was fixed at from 84 to 91 feet.

Expansion Joints. An expansion joint formed by building vertical faces of concrete blocks is shaped as a tongue-and-groove joint normal to face of dam, thus preventing a continuous opening through the dam. At each expansion joint a vertical inspection well is formed of concrete blocks. This will afford an opportunity for studying conditions at the joint, and should the leakage through

BOARD OF WATER SUPPLY OF THE CITY OF NEW YORK

Contract No. 3

MAIN DAMS, ASHOKAN RESERVOIR

Canvass of bids opened August 6, 1907

MacArthur Bros. Co., and Winston & Co., 11 Pine St., N. Y. City.

Item.	Description.	Unit.	Quantity.	Price.	Amount.
1	Removing steel pipes	Lump sum	....	....	10,000.00
2	Control of stream flow, Olive Bridge dam	"	....	....	10,000.00
3	" " middle dike	"	....	....	10,000.00
4	Earth excavation, Class A	Cu.yds.	95,000	$1.40	133,000.00
5	" Class B	"	50,000	2.50	125,000.00
6	" Class C	"	1,700,000	.68	1,156,000.00
7	" Class D	"	210,000	.50	105,000.00
8	Rock excavation, Class A	"	140,000	3.00	420,000.00
9	" Class B	"	210,000	1.60	336,000.00
10	" Class C	"	75,000	1.00	75,000.00
11	Special preparation of rock surfaces	Sq.yds.	40,000	.50	20,000.00
12	Embanking and refilling, Class A	Cu.yds.	2,500,000	.60	1,500,000.00
13	" " Class B	"	3,200,000	.60	1,920,000.00
14	" " Class C	"	1,200,000	.50	600,000.00
15	" " Class D	"	110,000	.50	55,000.00
16	" " Class E	"	45,000	.50	22,500.00
17	Soil for surface dressing	"	210,000	.50	105,000.00
18	Portland cement	Barrels	1,100,000	1.50	1,650,000.00
19	Concrete masonry	Cu.yds.	280,000	4.90	1,372,000.00
20	Cyclopean masonry, Class A	"	475,000	3.40	1,615,000.00
21	" Class B	"	55,000	3.90	214,500.00
22	Concrete blocks	"	64,000	11.50	736,000.00
23	Reinforced concrete	"	100	20.00	2,000.00
24	Masonry filling openings, control stream flow	"	8,000	1.50	12,000.00
25	Grout of Portland cement	Cu.ft.	5,000	.50	2,500.00
26	Drilling small holes in rock or masonry	Linear ft.	1,000	1.00	1,000.00
27	Face dressing of concrete	Square ft.	125,000	.10	12,500.00
28	Dry rubble paving	Cu.yds.	95,000	2.50	237,500.00
29	Riprap	"	10,000	1.50	15,000.00
30	Cast-iron pipes and special castings	Tons	75	101.00	7,575.00
31	Steel castings	"	80	150.00	12,000.00
32	Steel for reinforcing concrete	Pounds	25,000	.07	1,750.00
33	Wrought iron, cast iron, and steel	"	590,000	.08	47,200.00
34	Bronze work	"	4,000	.50	2,000.00
35	Furnishing and placing wrought-iron pipes	Linear ft.	2,500	.50	1,250.00
36	Caring for and setting metal furnished by city	Pounds	900,000	.02	18,000.00
37	Clearing	Acres	200	140.00	28,000.00
38	Vitrified pipes not exceeding 10 ins. in diameter	Linear ft.	11,500	.50	5,750.00
39	Vitrified pipes from 12 to 18 ins. inclusive in diameter	"	10,000	1.25	12,500.00
40	Crushed stone and gravel	Cu.yds.	11,000	1.25	13,750.00
41	Timber and lumber	M. ft. B.M.	950	50 00	47,500.00
	Total	....	....	.....	$12,669,775.00

Time, 84 months
Bond, $1,000,000
Engineer's estimate, $12,850,000

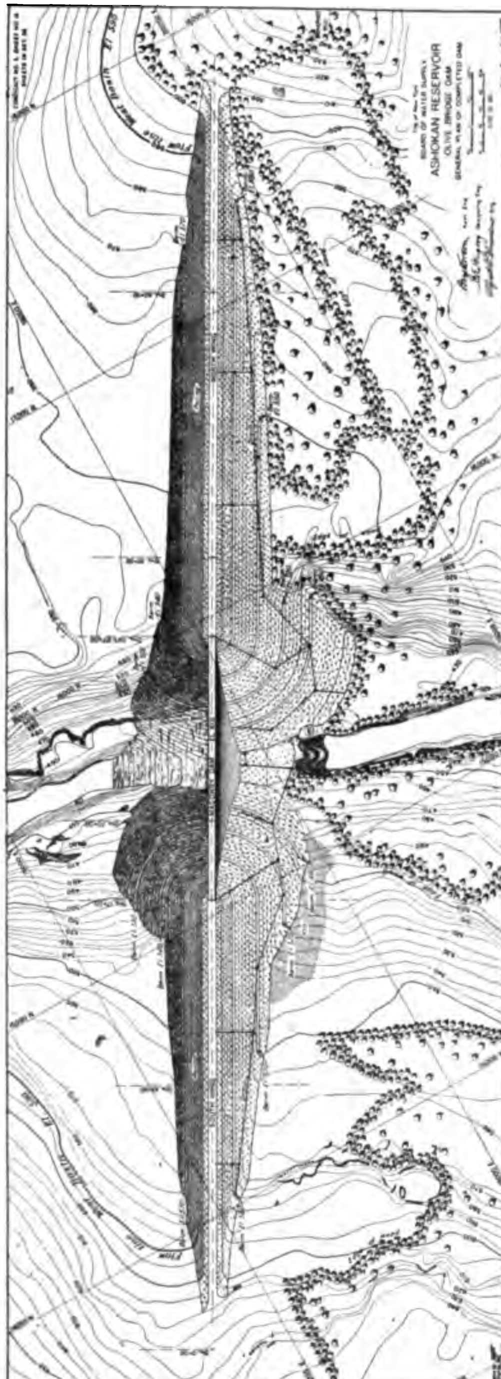


PLATE 26.—General Contour Plan of Olive Bridge Dam, as per Contract Drawings.

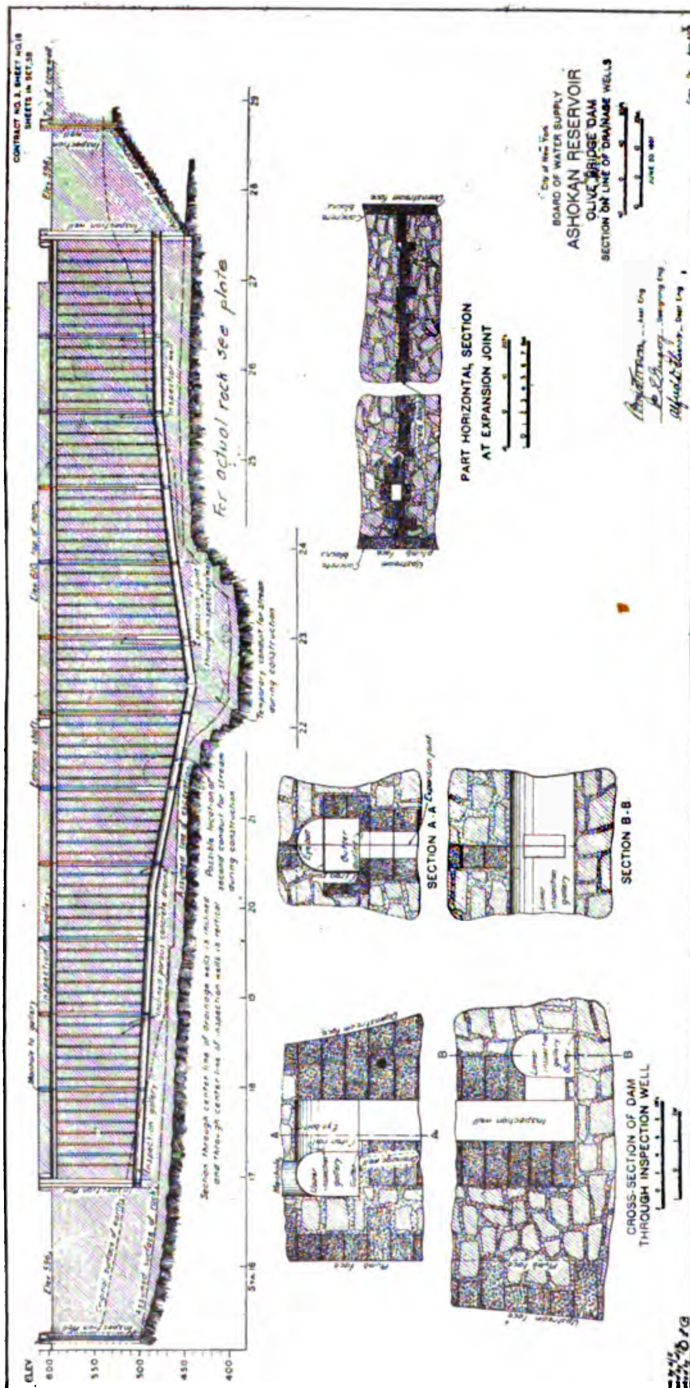


Plate 27.—Olive Bridge Dam. Contract Sections of Dam on Line of Drainage Wells. Inspection Galleries and Wells and Expansion Joint.

the joint be unduly large it may be filled with concrete or clay to act as a water stop. A copper strip may also be placed to act as a water stop. Connecting the vertical inspection wells are longitudinal galleries, one near the top of the dam, entered by manholes from the top, and the other in the lower portion of the dam near the base of the expansion joint. The lower gallery opens near the center of the dam into a transverse gallery leading to a drain at the downstream side of the dam. Inspection wells are from 15 to 20 feet from the upstream face of the dam. Between them, to intercept seepage and to turn it into the lower inspection gallery and drain, are other wells, 16 inches in diameter and about 12 feet apart. These are made by laying up large, hollow, porous concrete blocks. The water to be intercepted is that which may enter the body of the dam, either through the expansion joints of the inspec-

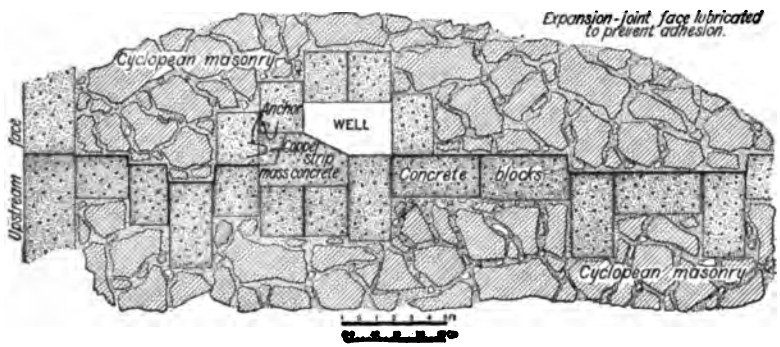


PLATE 28.—Transverse Expansion Joint in Olive Bridge Dam, Showing Drainage Wells.

tion well, or through the capillary spaces of the masonry, and it will be conducted by means of the wells, galleries and drains to the gorge below the dam.

To supply a dam with a drainage system may seem anomalous, but it is based on the extended experience of J. Waldo Smith, Chief Engineer, who has constructed several dams of this type.

Concrete Blocks, etc. The upstream and downstream faces of the masonry dam will be bounded by large concrete blocks which are cast and seasoned in the yard for three months. On the downstream side there are four different risers used; on the upstream, only one. These blocks are composed of headers and stretchers, every third block in every second course being a header. These blocks serve as a form for the cyclopean masonry hearting, and are used instead

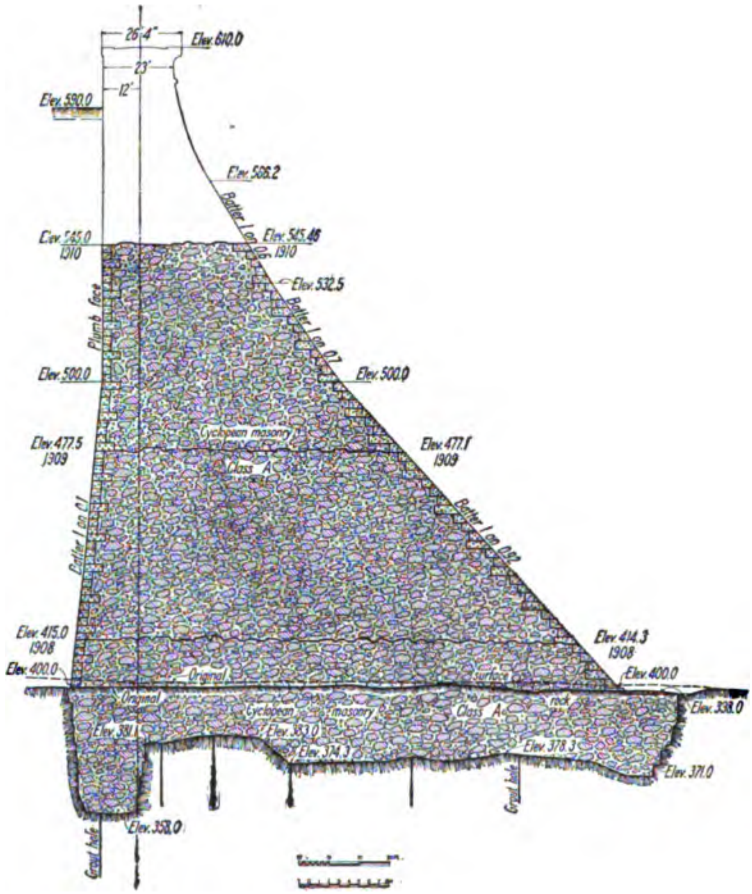


Plate 29.—Olive Bridge Dam. Maximum Cross-section, Showing Progress in Laying Masonry during Years 1908, 1909 and 1910. Unshaded Portion was Finished in 1911.

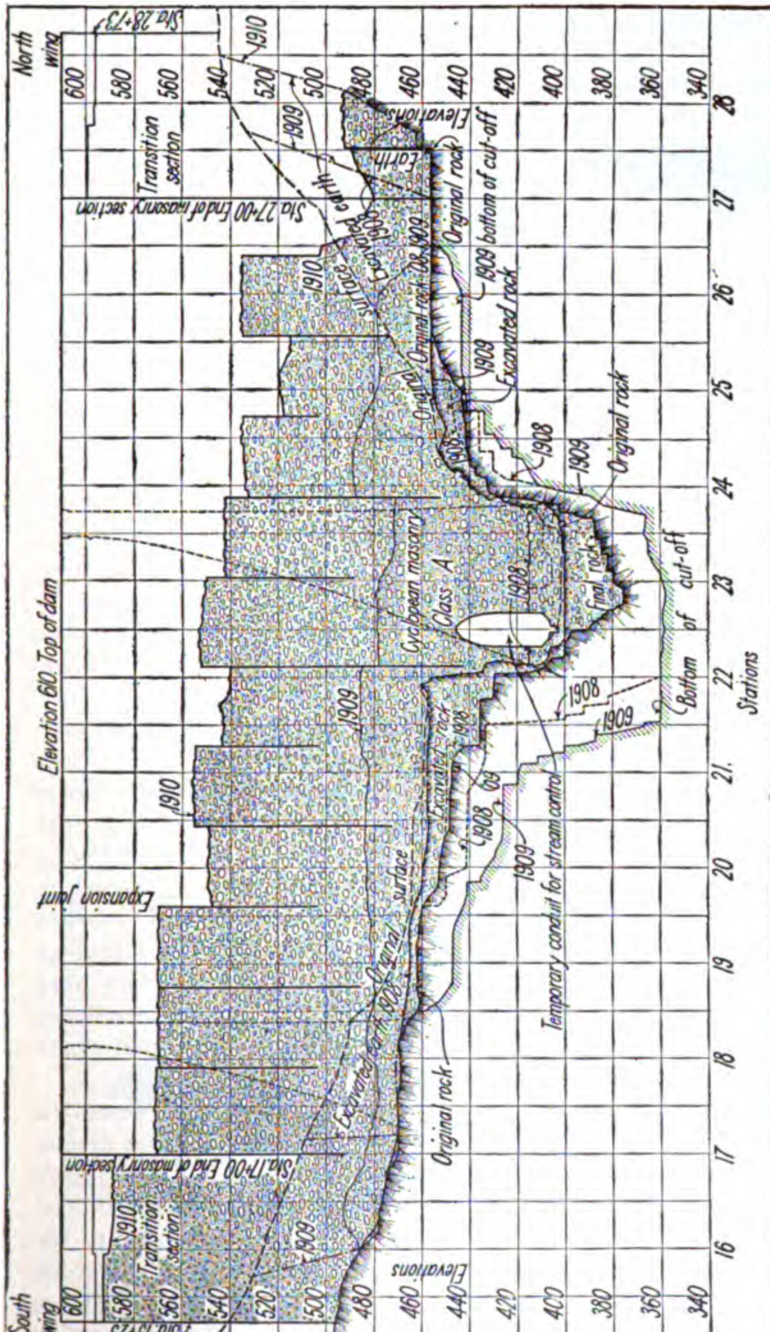


PLATE 30.—Olive Bridge Dam. Maximum Longitudinal Section, Showing Progress in Placing Masonry during 1908, 1909, and 1910. Unshaded Portion was Finished in 1911.

of ashlar, because they are cheaper and can be obtained in a much shorter time, particularly in this region remote from quarries of granite or other suitable stone.

The cyclopean masonry is composed of bluestone which can be conveniently quarried or handled. This stone is bedded in concrete, each being separately jogged into place in the soft concrete, the aim being to obtain the largest proportion of stone consistent with good work.

The division of the dam into sections by means of transverse joints bounded by blocks greatly facilitates the work, as one section can be run up higher than the next, thus increasing the efficiency of the derricks and plant.

Comparison of Olive Bridge and New Croton Dams. The dam has a maximum height of 210 feet above the original ledge rock in the bed of the stream. This was increased to 236 feet by excavating to sound rock, and to 252 feet to the bottom of the cut-off wall, which extends to about 42 feet below the original stream bed. The New Croton Dam has its crest 149 feet above the old river-bed of earth, 234 feet above ledge rock, and 294 feet above the lowest point of excavation. Its cross-section is much lighter than that of the Olive Bridge dam, particularly for the first 110 feet below the crest.

Beaverkill Dikes. Beaverkill dikes consist of the West dike, from Winchell Hill to Dividing Weir; the Middle dike, from the end of the West dike to Leonard Hill; and the East dike, from Leonard Hill to the Waste Weir. These dikes are earth embankment with concrete core wall founded on rock where it is within 10 feet of the surface of the ground, and where the rock is deep, on rock or hardpan. At the crossing of the Beaverkill, the core wall is arched and extends to the bottom of the preglacial gorge. The maximum height of the dikes above the ground is found here where they extend above the original surface 115 feet and above the rockbed of an old preglacial gorge, as excavated, 185 feet. The total length of the dikes is about 2.5 miles.

The Dividing Weir. The Dividing Weir extends from the junction of the West and Middle dikes to Green Hill and divides the reservoir into an East and West basin. The north portion will be built of masonry with an overflow section over which the flood flow will pass from the West to the East basin on its way to the Waste Weir. The south portion, or Dividing Weir dike, will be an earth embankment. The weir portion is founded on solid ledge rock. Footings for piers for a bridge are to be built in connection

PLATE 31.—View of Downstream Face of Completed Olive Bridge Dam, Showing Esopus Gorge.

with the Dividing Weir. Below the weir an excavation forms a shallow discharge channel. The weir is about 1100 feet in length, the embankment or dike portion 1100 feet.

The gate chamber is constructed in the dike portion of the Dividing Weir, of concrete, with openings into each basin of the reservoir. The superstructure, gates and machinery of this chamber are furnished under other contracts.

Pressure Aqueducts. Two aqueducts, one above the other, in a deep-channeled trench, will extend from the gate chamber through and under the Dividing Weir dike and Middle dike, to a point near the toe of the slope of the latter, where they will connect with the Catskill Aqueduct through a lower gate chamber, etc., built under Contract 10. These aqueducts will have a length of 560 feet, and are constructed to withstand an internal pressure due to the depth of water in the reservoir.

Inlet Channels. The East and the West inlet channels are constructed in open cut from the deeper portion of the East and West basins, to the gate chamber. The East channel in rock is 3000 feet long with a maximum cut of about 80 feet. The West channel, mostly in earth, is 5800 feet long, with maximum cut of about 80 feet. These channels average about 40 feet in depth of cut.

Required Progress. The contract requires as scheduled below:

Time elapsed after service of notice to begin work.	Percentage to be done of total amount of contract, based on contract prices.
9 months	2 per cent
16 "	9 "
28 "	23 "
40 "	41 "
52 "	61 "
64 "	80 "
76 "	96 "
84 "	100 "

In addition, the contract provides that the Olive Bridge dam, West dike, Dividing Weir, pressure aqueducts and gate chamber shall be completed to at least elevation 520 at their lowest points, and the West channel completed ready to impound and deliver water within 54 calendar months.

In its present position, the railroad runs through the heart of the reservoir, blocking important work at several points. Recently (in 1911) an agreement was reached with the Railroad, and the construction upon the new location started by Winston & Co. This will put off the time when water can be impounded to some time in 1913 instead of 1912.

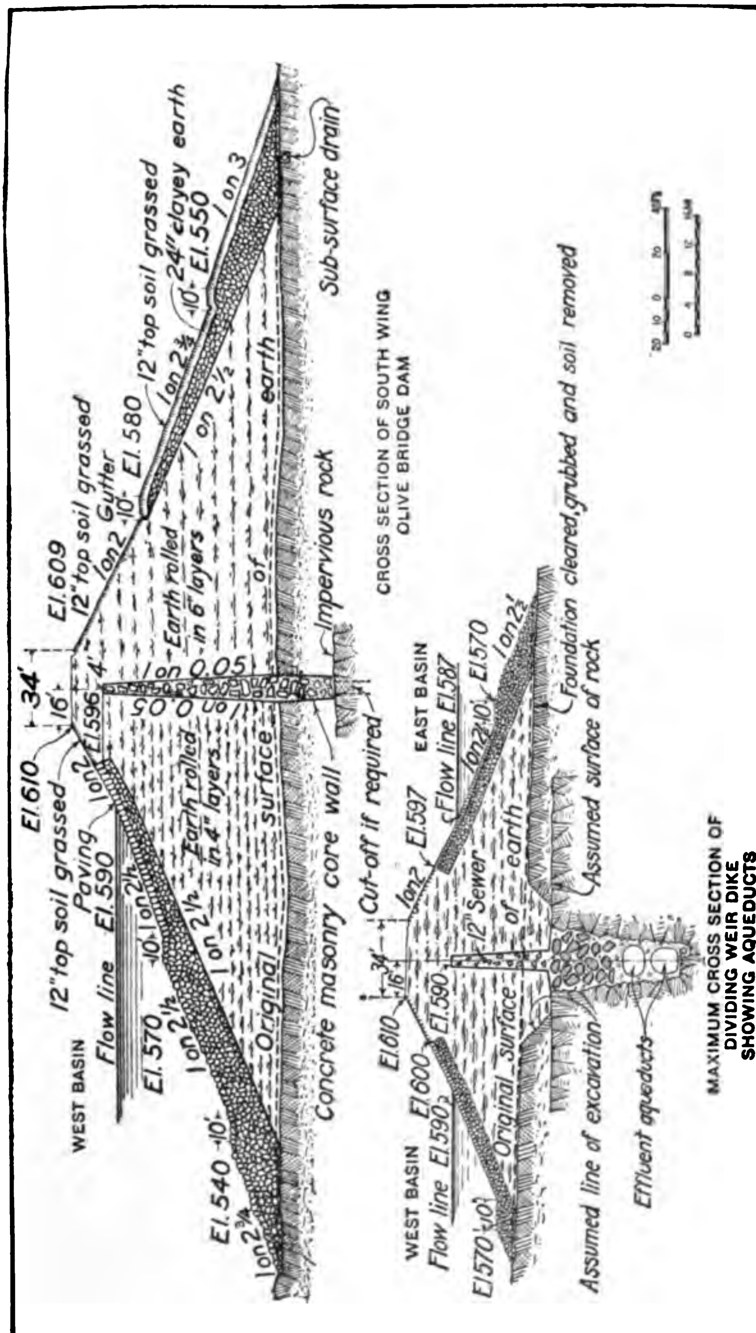


PLATE 32.—Ashokan Reservoir. Typical cross-section of earth embankment and Dividing Weir Dike over Pressure Aqueduct.

Specifications of Contract 3. Some important provisions of Contract 3 are abstracted below:

General Statement. Section 36. "During the construction of the main dams the ordinary and flood flows of Esopus Creek, Hog Vly Kill, and Beaver Kill must be safely carried over and past or diverted from the sites of the Olive Bridge dam, West and Middle dikes, respectively, in such manner as will permit, as far as possible, uninterrupted work on these structures.

Esopus Creek Watershed. Section 37. "The area of the watershed above Olive Bridge dam is approximately 240 square miles. There is practically no natural storage on the watershed. A flood flow of 38,000 cubic feet per second has been estimated at Olive Bridge and may be exceeded. Floods of 15,000 cubic feet per second may be expected each year.

Beaver Kill Watershed. Section 39. "The watershed of the Beaver Kill above the site of the Middle dike is approximately 17 square miles. It is estimated that a maximum flood of 2500 cubic feet per second may occur. The watershed contains a large percentage of swamp area which will probably afford considerable natural storage.

Steam Control Works Installed by Board. Section 41. "Two cofferdams, two 8-foot steel pipes, and pumping plants installed by the Board will probably be in operation in the gorge of Esopus Creek, at Olive Bridge dam site, at the date of execution of the contract, as mentioned in the information for bidders. Within thirty days after the service of the notice instructing the Contractor to begin work, he shall take over and operate these controlling works, including the two cofferdams, the two 8-foot steel pipes, and the Brooks centrifugal pump, with 12-inch suction and 10-inch discharge, and direct-connected Sturtevant engine. . . . When directed, the Contractor shall disconnect and carefully remove, in sections not exceeding 30 feet in length, the two 8-foot steel pipes, and store the sections at a designated place within 2000 feet of their position in the gorge. These steel pipes shall remain the property of The City. In making his bid under Item 2, for controlling works for Esopus Creek, the Contractor shall make due allowance for these existing works and for the Brooks pump and engine, as specified in this section.

Section 46. "Until the general level of the masonry dam shall have been raised to elevation 470, and at such other times as directed, a portion of the masonry dam, between two expansion joints located

PLATE 33.—Olive Bridge Dam. View of Gorge of Esopus Creek and Stream Division of 8-foot Pipes to Carry Normal Flow of Esopus Creek over Foundation of Dam.

near the center of the gorge, shall be kept depressed about 10 feet below the level of the other masonry.

Excavation for Core Walls. Section 77. "Excavations for the core walls at each end of the Olive Bridge dam, and for the core walls of the Beaver Kill dikes and the dike portion of the Dividing Weir shall be made of sufficient depths to secure acceptably, sound and impervious foundations, and of sufficient widths either to contain the masonry, placed directly against their sides, or to allow for acceptable sheeting, bracing and forms outside the prescribed masonry lines. Core wall trenches, not more than 20 feet wide on the bottom and 20 feet deep, shall, in general, have approximately vertical sides and, if directed, be braced and sheeted as herein provided. Other core wall trenches are expected to have side slopes of 1 vertical on 1 horizontal, but may, when permitted, have steeper slopes if sufficient to insure stability during the progress of the work.

Section 78. "Whenever a core wall is to be built on rock, the rock shall be thoroughly cleaned and all cracks and seams raked out and filled with mortar or grout.

Classification of Excavated Earth. Section 80. "Excavated earth shall be classified for payment as follows:

"Class A, Item 4, shall include earth excavated from depths less than 20 feet in trenches less than 20 feet wide on the bottom with sides approximately vertical for the whole or a part of their depth. . .

"Class B, Item 5, shall include earth excavated from the depths below 20 feet in trenches less than 20 feet wide on the bottom with sides approximately vertical for the whole or a part of their depth. . . This class shall include also earth excavated from the Beaver Kill gorge from depths below 20 feet, and other similar deep excavations, if any be ordered.

"Class C, Item 6, shall be earth excavated for the Olive Bridge dam, between Station 15+23 and Station 28+73, including the cleaning of the gorge, for the gate-chamber, for the inlet channels, for the aqueducts, and for the Waste Weir and Dividing Weir, with their adjacent channels, and the portions of the lengths of the trenches for core walls wherever for their full depths they have side slopes flatter than 6 vertical on 1 horizontal. Class C shall include, also, earth from miscellaneous excavations for grading, for highways and for building temporary roads for the purpose of maintaining traffic on the present highways, and from all other excavations not specifically enumerated.

"Class D, Item 7, shall include top soil removed from the sites of the excavations and embankments as provided in Section 71, but shall not include top soil excavated from other areas for the purpose of completing the surface dressing of embankments or other graded areas.

Measurement of Trenches. Section 81. "All trenches with approximately vertical sides to be paid for under Items 4 and 5, shall be measured as having side slopes of 6 vertical on 1 horizontal and the designated bottom widths. Trenches and other excavations having side slopes flatter than 6 vertical on 1 horizontal shall be measured as if the side slope were 1 on 1, excepting in such cases as flatter slopes shall have been expressly ordered, in which cases the slopes ordered shall be used for purposes of measurement.

Rock Excavation for Olive Bridge Dam. Section 82. "Rock is to be excavated for the masonry portion of Olive Bridge dam to a sufficient depth to secure a foundation on sound ledge rock, free from open seams, or other objectionable defects. A cut-off trench will be required near the upstream side of the foundation, under the whole or a part of the length of the masonry dam. It is the intention to build the masonry against the sides of these rock excavations. To preserve these sides in the soundest possible condition, and to obtain over the whole foundation a rock surface free from seams or cracks, unusual precautions will be required in the excavation. Rock for the foundation of the masonry portion of the Olive Bridge dam shall be removed by channeling, drilling and wedging, barring, or other similar methods. No blasting shall be done except by special permission, and only then with light charges of explosives. The rock excavation from the cut-off trench shall be removed only by channeling or other acceptable method.

Rock Excavation for Core Walls. Section 83. "Wherever the rock is not sufficiently sound at its surface for the foundation of a core wall, excavation shall be made to the extent directed and in the manner prescribed for rock excavation under the masonry portion of the Olive Bridge dam.

Section 85. "Excavations similar to those specified in Section 82 shall be made for the Dividing and Waste weirs; but the requirements for their foundations may be less exacting because these structures are much lower and subject to different conditions.

Rock Excavation in Esopus Gorge. Section 89. "Projecting, overhanging, unsound and loose rock shall be excavated to the extent directed from the sides and bottom of the Esopus gorge above the Olive Bridge dam, from areas that are to be covered by embankments, and from such other areas in the gorge as may be designated.

Care shall be taken in the removal of this rock not to loosen nor injure the remaining rock.

Preparation of Rock Foundation for Masonry. Section 90. "The surface of the excavations for rock foundations shall be left sufficiently rough to bond well with the masonry. The rock foundations for any structure, if required, shall be cut to rough benches or steps. Before any masonry is built on or against the rock, it shall be scrupulously freed from all dirt, gravel, boulders, scale, loose fragments, and other objectionable substances. Streams of water under sufficient pressure, stiff brushes, hammers or other effective means shall be used to accomplish this cleaning. Steam jets shall be used to thoroughly remove ice or snow, if any be found on the rock, when it is desired to lay masonry.

Classification of Excavated Rock. "Class A, Item 8, shall include all rock excavated from the foundation of the masonry portion of the Olive Bridge dam, for the core walls, for the Dividing Weir and Waste Weir, and all rock excavated for the aqueducts, beginning at a point on their center line 60 feet southerly from the intersection of the center line of the inlet channels and the aqueducts.

"Class B, Item 9, shall include all rock excavated from the channels and retaining walls adjacent to the Dividing and Waste Weirs, (except the core wall of Dividing Weir dike), for the inlet channels and adjacent retaining walls, and for the gate chamber between a point 60 feet southerly from the intersection of the center lines of the inlet channels and the aqueducts and the northerly outer face of the foundation walls of the gate chamber.

"Class C, Item 10, shall be all other rock excavated, except from quarries, borrow pits, or for purposes of the Contractor, and not included in Classes A and B. In this class shall be included all boulders of 1 cubic yard or larger in any ordered excavation.

Rock Trenches. Section 92. "Rock trenches for drains and rock excavation for other minor structures not otherwise designated, shall be measured as of the bottom dimension stipulated herein, or ordered, and as if the rock were taken out with side slopes of 6 vertical on 1 horizontal. Before measuring, the surface of ledge rock shall be cleared of earth, boulders, and other encumbrances, which would interfere with correct measurement. The areas of rock surfaces so cleared at any one place or time shall be of reasonable extent. Whenever any portion of the ledge rock of any boulders are ready for measurement, the Contractor shall notify the Engineer, and only that rock will be paid for which shall have been properly measured.

Preparation of Base for Embankments. Section 98. " Embankments shall start from a firm base from which soil and other perishable matter shall have been removed to the extent directed, as provided under Sections 71 and 251. If required, the base under the embankment shall be picked to make a bond with the embankment material, and on sloping ground shall be stepped where and as directed.

Control of Springs. Section 99. " Springs encountered on the sites of the embankments shall be controlled by plugging or draining, or by other approved methods. Masonry, pipes, grout, broken stone, cement, or other materials used, or excavations made for such control shall be paid for under the appropriate items, as determined by the Engineer. In general, springs encountered on the downstream side of a core wall shall be led into the drainage system at the downstream toe of the embankment.

Allowance for Shrinkage. Section 103. " The embankments shall be built to a height above the finished grade, which will, in the opinion of the Engineer, allow for the shrinkage of the material. If such ordered overfill results in an excess section of any embankments, the Contractor shall be allowed payment for such excess. If any of the embankments or refillings settle so as to be below the required levels for the proposed finished surface at any place, before the final acceptance of the work to be done under this contract, the Contractor shall, at his own cost and expense, supply approved materials and build up the low places as directed.

Classification of Embanking and Refilling. Section 106. " Embankments and refills shall be classified for payment according to their physical characteristics and special requirements, as follows:

" Class A, Item 12, shall include the impervious embankments and refills of selected fine earth, deposited and compacted as hereinafter specified, on the upstream sides of the core walls of the dam and dikes, excepting the Dividing Weir dike, on the upstream side of the masonry dam (excepting the portion deposited through the water after the reservoir shall have been partially filled with water), and the refills, below the bases of the embankments, against the downstream faces of core walls.

" Class B, Item 13, shall include the embankments of selected earth, deposited and compacted as hereinafter specified, on the downstream sides of the core walls of the dam and dikes above the bases of embankments and on the downstream side of the masonry dam, the embankments and refills of the Dividing Weir and the Waste

Weir, and the embankments above the tops of the core walls, on both sides of the dam and the dikes.

"Class C, Item 14, shall include the layer of durable boulders, stones and rock fragments of any size and shape placed as hereinafter specified on the upstream and downstream surfaces of the dam, the dikes, and the weirs, except the paving and riprap to be paid for under Items 28 and 29. The layer of clayey earth placed on top of the stony layer on the downstream sides of the dam and dikes, to support the top soil, shall also be included in Class C. The quantity of Class C material to be deposited on the downstream side of the dam and dikes will vary with the nature of the material from excavations and borrow pits, but will extend approximately within the sloping lines shown, over at least one-third of the height of the dam and dikes where shown on the contract drawings.

"Class D, Item 15, shall be the fine earth deposited through the water, after the partial filling of the reservoir with water, on the upstream side of the Olive Bridge dam.

Class E, Item 16, shall include all embankments and refills shown on the drawings or specifically ordered, not included in Classes A to D, both inclusive, except embankments or refills made by the Contractor for his own use or convenience."

Care in Foundation Work. Particular attention is called to the great care required in the preparation of the foundation for the main dam and core walls and the power given to the engineers to secure special treatment for the bottom and sides of the gorge, also the care demanded in excavating. These precautions were also fair to the contractor, as opportunity was given to him to bid on several classes of excavation in proportion to the care demanded. Another feature working toward the same ends is the division into several classes of earth embankment, in accordance with the necessity for imperviousness above or below the core walls, etc.

Payment Items. Another feature of all Board of Water Supply contracts is the division into a number of payment items. This makes for more exact bidding and estimating, and greatly facilitates estimating both before and during the construction. It also aids in exact specification and description of the work to be done. In connection with each item is a section of the specification, defining exactly how measurements are to be taken in estimating each. This will be appreciated by anybody who has taken part in litigation over payment on contracts.

General Preparations. Soon after the contract was awarded, active preparations were made to install an equipment preliminary to vigorous prosecution of the work. A striking feature of the prosecution of this work was the apparent unity of purpose shown by the contractor. Railroad connection was established with the Ulster & Delaware Railroad at Brown's Station. A large machine shop, power plant, central crushing plant, quarry, and a very large camp were established.

Contractor's Camp. As the country in the vicinity of this contract is sparsely settled, it was necessary to establish a camp at the very start of the work. The camp was laid out at the beginning in streets with all the necessary conveniences for accommodating a maximum number of workmen. The site of the camp was just below the dam on a bluff overlooking Esopus Creek. It was overgrown by a thick second-growth woods, and many of the trees were left standing. It has a natural drainage to Esopus Creek. In accordance with the terms of the contract a sewage disposal plant was built and sewers laid throughout the camp. Water is provided for drinking and sanitary purposes, and for fire. The drinking water is from a spring of pure water. Several of the streets are paved and lighted by electricity. Garbage and ashes are collected and disposed of daily.

Camp Buildings. A school, hospital, bakery, store, bank, ice-house, etc., have been provided. The barracks, dormitories, dining hall and cottages have all been built in a substantial manner. A typical four-room house for laborers with families is $16' \times 40'$, with extension $12' \times 12'$, rough boarded on the outside and sheathed with plain matched boards on the inside. The roof and sides are covered with rubberoid or Amazon paper, making it warm and weather proof. The floors are double, with paper between. Such a house costs about $400, not including a sewer and water system, and rents for $15 monthly, including all fuel, water and sanitary protection. In the quarters for laborers without families, the buildings are arranged as barracks and dormitories, the former being divided into rooms containing two double and one single bunk, the charge being $1.50 to $2 per month. The store is very large and contains all supplies at reasonable prices. It is not a commissary, but does strictly a cash business, and prices here compare very favorably with outside stores. The hospital is very well equipped. The unique feature of this camp is a night school for the instruction of adult laborers in the English language, etc., the same school being used for children in the daytime. The bank, known as the Ashokan Bank, is supported by the contractors, and in the same building are halls used as club rooms, etc. The superintendents and engineers of the contractors are provided with well built and pleasantly located bungalows. Altogether this camp is provided with more conveniences and is more comfortable than any of the villages in the neighborhood. In addition to the above, smaller camps are maintained at various other points convenient to the work.

Contractor's Railroad. The contractor's railroad is standard gauge and equipped with rolling stock comparable to many public carriers. The railroad organization is separate from the construction force and business is carried on in much the same way as a public road. The main line, double tracked, runs from its junction with the Ulster & Delaware Railroad at Brown's Station to the main plant at Olive Bridge dam. At this point numerous side tracks are laid to the block yard, cement house, coaling siding, compressor plant, crusher, and unloading tracks under the four main cableways which serve the dam. The line continues to the Yale quarry, crossing Esopus Creek three-quarters of a mile from the dam on a steel viaduct 85 feet high and 390 feet long, entering the quarry about 2½ miles from the dam on a switchback. The line is double tracked to the Esopus. Leading off from this point, there is a single-track branch to the sandpits. Near the power plant is a line leading to the west dike around Winchell Hill. There are two more branches leading off this line to the north wing, one of which supplies sand, stone and cement to the concrete mixing plant, the other delivers the earth for embankment. The Middle dike branch leaves the main line near Brown's Station and crosses the Ulster & Delaware Railroad twice with overhead crossing. Spurs are laid from this branch to the Dividing Weir, to the Aqueduct, and to the discharge channel. The rolling stock of the railroad consisted of nine 40- to 65-ton American locomotives of the saddle tank type; 115 flat cars equipped with air, 4 gondolas, 72 6-yard Western side-dump cars, and about 250 narrow-gauge 4-yard cars with 14 narrow-gauge 18-ton Porter locomotives. An American hoist locomotive crane was also a part of the rolling stock, being used to lay track, erect overhead bridges, and for miscellaneous purposes. The total trackage, including all branches, was about 20 miles, all of heavy rail laid on first-class ties. The maximum grade was 2½ per cent. This railroad during its life has handled an enormous tonnage, consisting of all the incoming freight for the work and camps, transportation of stone, concrete material, concrete blocks to the four cableways, and other plants, and in addition, great quantities of earth for the embankments.

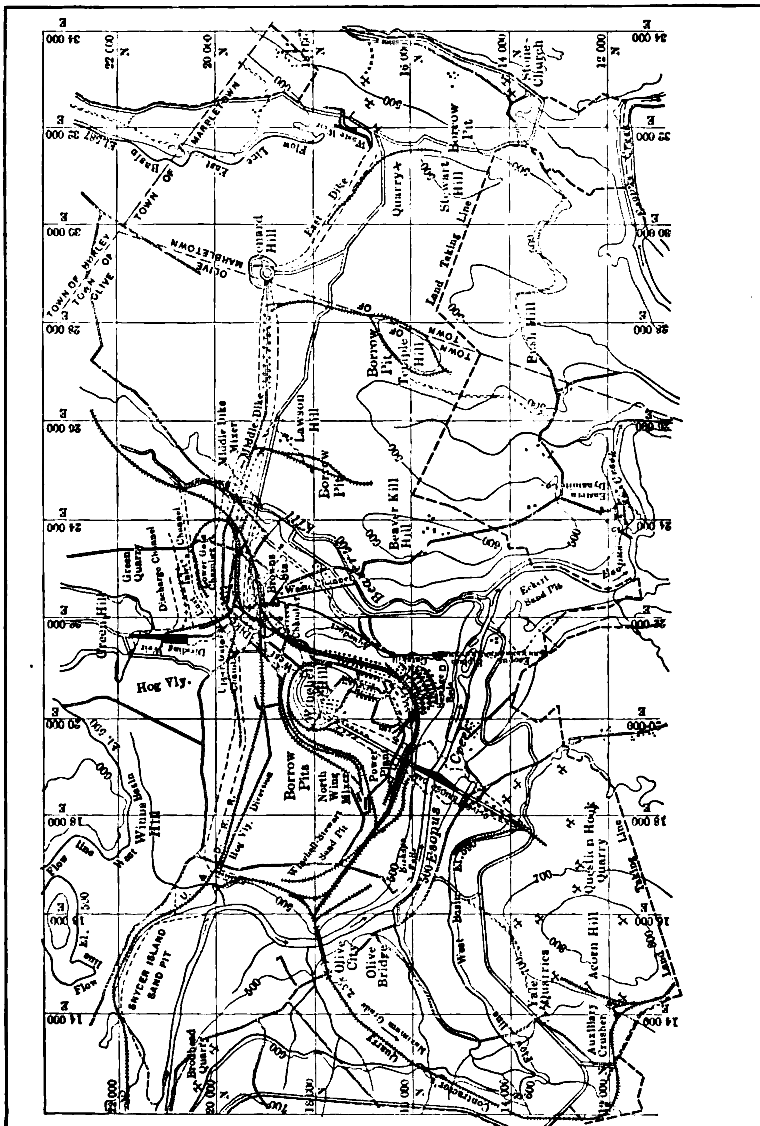


PLATE 34.—Contract 3. Layout of Contractor's Plant and Railways, Showing Location of Camp, Borrow-pits, etc.

Compressor Plant and Use of Compressed Air for Power. This plant was established at the beginning of the work at a point convenient to the dam and railroad. It consisted of a battery of five 265-H.P. Babcock & Wilcox water-tube boilers which furnished steam to four air compressors built by the Ingersoll-Rand Co. Two of these machines of 500 H.P. each were previously used at the Wachusett and Cross River dams. The other two were new and rated at 450 H.P. each. Their engines were compound-condensing with compressors furnished with inter and after coolers. The large machines had a capacity of 3500 cubic feet of free air per minute, the smaller 2500, making a total of 12,000 feet. Two dynamos installed in this plant are used for furnishing current for lighting the work and the camp. The coal used by this plant and by the railroad was stored in bins under a trestle. About 1400 tons of coal monthly were used for all purposes. The compressed air was carried in pipes of 12 to 4 inches to nearly all parts of the work, including the Yale quarry 2 miles distant, delivered at about 80 pounds pressure. It was used for a great variety of purposes, operating the cableways, all the derricks, and pumps, and many rock drills. This plant illustrates well the adaptability of compressed air to work covering a great area, and the economy and durability of a central compressor plant.

Olive Bridge Dam Foundation. The Olive Bridge Dam is 4620 feet long, including the masonry portion 1000 feet long. It contains about 420,000 cubic yards of cyclopean masonry, 56,000 yards of concrete blocks, and about 2,000,000 cubic yards of embankment. The Board of Water Supply in order to save a season's work, installed two 8-foot riveted pipes to carry the ordinary stream flow, and exposed the creek bottom under the dam by two crib cofferdams. These pipes remained in commission until the cyclopean masonry with an arch conduit built in it reached their level. The Esopus had eroded a channel about 220 feet wide and 40 feet deep with nearly perpendicular sides. The bottom layer was a thick bed of bluestone with many open seams. It was carefully excavated to sound rock at a maximum depth of 30 feet below the original surface of the bed.

Cut-off Trench. A cut-off trench 20 feet wide reached across the channel just below the upstream edge of the dam, and was excavated to about 40 feet maximum depth. This cut-off channel was carried into the side walls of the gorge, the bottom being stepped up when the character of the rock was good. All loose and unsound rock was excavated from the sides of the gorge. Below the top layer

PLATE 35.—View of channeled Cut-off-trench under Upstream Face of Olive Bridge Dam. Two 8-foot Steel Pipes Carrying the Flow of Esopus Creek.

PLATE 36.—Cut-off Trench, Olive Bridge Dam. Shows Channeled Rock and Masonry in Trench; also Main Cableways and Derricks.

of the bluestone was found alternating layers of slate, shale and bluestone. Geologists state that when the shale was relieved of its superimposed load of other strata by the cutting of the Esopus gorge, it expanded and developed seams along the bedding plane. The limit of rock excavation was determined by the extent of these seams which decreased in number with the depth, extending to greater depths at the center of the gorge, with the result that the excavation was in a series of steps. The cut-off trench intercepts all seams to a depth of 40 feet below the bed of the stream.

Grout Holes. As a still further precaution a row of 3-inch grouting holes was drilled 20 feet below the bottom of that trench, reaching the greatest depth at which the pressure tests had indicated the presence of seams. Similar grouting holes were drilled to about the depth of the cut-off to insure the sealing of any seams that might exist in the rock under the main body of the dam; 255 holes were drilled, aggregating 2707 feet. Two-inch iron pipes were cemented in the tops of the drill holes and carried up into the masonry to permit grouting when the dam had reached sufficient height to withstand the pressure of the grout.

Diamond-drill Holes to Test Rock Foundation. It might be interesting here to describe the borings made under the dam foundations. Nineteen diamond-drill holes were put down in the bed of the stream and adjacent rock sides. Some of the holes reached a depth of 100 feet below the bed of the stream and were tested at each foot in depth for seams. These tests indicated small seams near the surface of the rock and two other general seams at depths of 40 and 60 feet below the bed of the creek, extending in the rock for the full width of the dam but not far beyond the sides of the gorge. Beneath the lower of these seams the test showed the rock to be entirely free of seams. The rock excavation for the dam developed all the seams indicated by these tests, but did not disclose any additional ones or any characteristics in the rock not indicated by the experiments. The communication from one hole to another through the seams was shown by water dyed with "uranine."

Main Cableways. To aid in the excavation for the foundations for the dam and for building the masonry section four Lidgerwood traveling cableways were installed, each having a clear span of 1530 feet, a lifting capacity of 15 tons and a speed of 1200 feet per minute. The cableway towers were about 90 feet high, running on tracks 150 feet above the bed of the stream. The tracks were 600 feet long and in three sets, one track of three rails, and two of two rails each. The hoisting engines were on the towers on the north bank and operated by compressed air from the power house. The tail towers had engines used only for the purpose of moving cableway along the tracks. Near the towers on the north bank eight standard gauge tracks were operated under the cableways.

Rock Excavation. In general, the lines along the edge of the rock excavation for the dam were cut with Sullivan channeling machines, after which light charges of powder were used to break up the rock which was then loaded into large skips raised by the cableways and dumped to form rock cones. This excavation required a very large amount of channeling, as shown in Plate 36. The cableways proved to be invaluable for placing excavating machinery in the gorge and delivering materials to the south bank, otherwise inaccessible. Every effort was made to complete the rock excavation and the dam to the level of the temporary steel pipes during the season of 1908. Work on both rock excavation and masonry was therefore carried on night and day. From the 1st of June till the end of the season there was only one delay of two days, when the flood was too great for the 8-foot pipes to carry.

Work of First Season (1908). There were excavated during this season 60,000 cubic yards of earth and 41,000 cubic yards of rock. About 26,000 cubic yards of masonry were placed. The stream was diverted through the opening of the dam, and the 8-foot pipes removed in December, after which the work shut down for the winter. At this time the general level of the masonry was about 15 feet above the bed of the stream, except at a portion of a cut-off trench where the rock excavation into the wall of the gorge was not completed. Considering the immense amount of plant which had to be installed before this work could be done the above is certainly a remarkable showing.

Grouting under Dam. The grout pipes built in with the dam were grouted with neat cement by the use of a Cockburn Barrow Machine of 4 cubic feet capacity, operated under a pressure of 25 to 80 pounds. The holes were drilled by large Ingersoll-Rand piston drills to a maximum depth of 30 feet, requiring the use of extraordinarily long steel drill rods. The 45 holes which went below the lowest seam took about 175 cubic feet of grout, the remaining 172 holes tapping the upper seam taking 925 cubic feet of grout.

Main Crushing and Concrete Plant. On the north bank just above the dam, where it could be served by the numerous tracks of the railroad, a very large central concrete and crushing plant was housed in a building 80′×100′ and 62 feet high. All the machinery was belted from two main shafts driven by 250-H.P. engine supplied

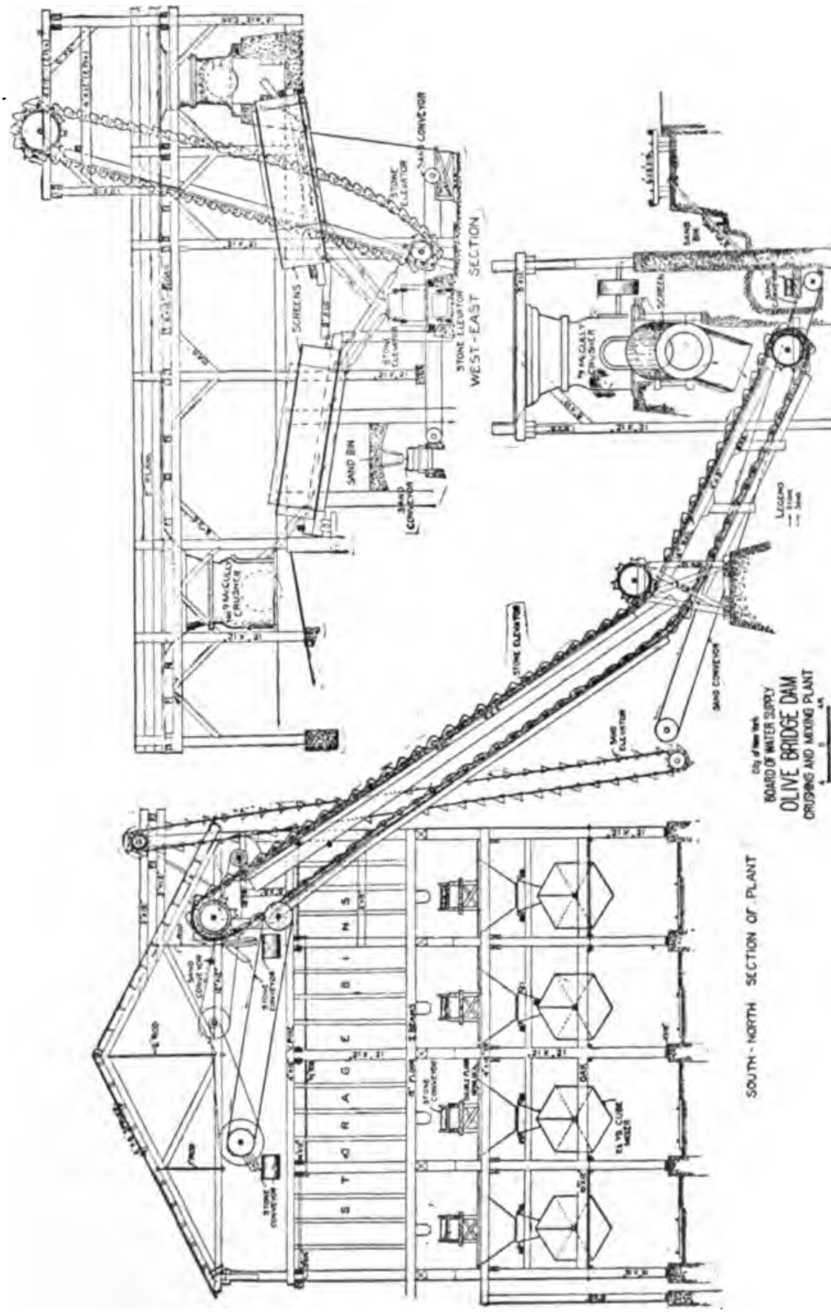


Plate 37.—Cross-section of Crushing and Mixing Plant Used at Olive Bridge Dam, Showing Layout of Machinery.

with steam through a 6-inch pipe from the boilers of the main power house about 150 feet distant. Stone from the quarry was delivered in 5-yard steel skips, four to a flat car. Two stiff-legged derricks dumped the skips directly into the crushers, one No. 9 McCulley, and two No. 6 Austin crushers, the latter recrushing the oversize stone. The crushers had a combined capacity of 100 cubic yards per hour. After passing through $2\frac{1}{4}$-inch holes in a revolving screen, the stone was elevated to the top of the building by an inclined link belt conveyor 88 feet long having 24″×30″ buckets. This conveyor discharged into a chute which delivered the stone to two 30-inch link belt conveyors 90 feet long which traversed the full length of the building over the top of the storage bins, capacity 800 cubic yards. Movable trippers enabled the stone to be dumped at any point in the bin, thus keeping the latter properly trimmed without any hand work. The screenings were delivered through a chute to a conveyor belt below the crusher floor which discharged them on the sand conveyor belt, thus mixing the dust and fine stone uniformly with the sand. The rejects were automatically delivered by a conveyor to the No. 6 crushers. The crusher plant usually operated in two shifts, working from 12 to 17 men.

Sand Supply. Seven-yard side-dump cars delivered the sand to a storage bin below the ground which had concrete walls. This bin, capacity 500 cubic yards, delivered by gravity to a belt conveyor which received also the stone dust and screenings mentioned above. This conveyor discharged into a bucket elevator running to the top of the building, whence the sand was distributed by a conveyor in the same manner as described for the stone bins. The crusher dust usually ran about 40 per cent of the fine material used in the concrete. The side-dumping cars were loaded at the Winchell Stewart sandpit by a Page drag-line excavator, 7 men working one 8-hour shift per day, and in 248 days during 1910, about 130,000 cubic yards of sand were taken out of this pit.

Cement Delivery. Cement of Alsen and Giant brands was unloaded by hand from the box cars directly into the cement house, of 18,000 bag capacity, adjoining the mixing plant. An inclined belt conveyor, 24 inches wide and 60 feet long, delivered the cement bags from the storage house to the charging platform, where they were deposited on the floor or delivered to an auxiliary horizontal belt conveyor 40 feet long which ran to the charging hoppers. The bags were emptied by hand into the charging hoppers at the mixers.

Concrete Mixers and Their Supply. The stone and sand bins were about 24 feet above the ground and are provided with horizontal steel gates operated from the charging floor. The stone was delivered to the charging hoppers by a 24-inch horizontal convey belt which ran underneath the eight stone gates. The sand was delivered in a wooden car, about 40 cubic feet capacity, loaded under the bins, and dumped into the charging hopper. The four charging hoppers discharged directly into four Keltenbach & Griess 5-foot cubical mixers, each of which could turn out about twenty 2½-yard batches per hour. The mixers discharged into Steubner bottom-dump buckets on flat cars on 3-foot gauge tracks on which they were drawn by mules either to the adjacent block yard or to the four main Lidgerwood cableways. The mixers worked one shift with a total force of thirty men.

The Block Yard. The yard was located near the concrete plant and occupied an area of about 600′×200′. Two 3-foot gauge tracks extended through the center of the yard; on them, mounted on trucks, was moved a 15′×25′ platform, about 6 feet high. Between these tracks and on each side, were four lines of molds. There were about 425 forms for blocks in use, the concrete being shoveled in them by hand from the movable platform. Along each side of the yard were placed five 10-ton derricks. These derricks had 75-foot masts with 70-foot booms, and were so guyed as to swing a full circle without lowering the booms. The engines were 7″×10″, and were operated by compressed air from the main plant. These derricks lifted 2½-yard Steubner buckets from the flat car onto the platforms, the newly made blocks from the molds to the storage pile, and from the storage piles to flat cars running on narrow-gauge loading tracks parallel to the yard and just outside of each row of derricks. These cars were run beneath the cableway which delivered them to the dam, where they were set by the derricks. The molds were five-sided, each side separate, but tied together by detachable bolts when used for forming the blocks.

Casting Concrete Blocks. The blocks contained from 15 to 65 cubic feet of concrete. They were cast face down on a carefully formed piece of steel covered with crude vaseline. The movable platform was run over the forms and the concrete shoveled directly into them, two men spading and leveling the concrete. The blocks were loosened from the forms forty-eight hours after being cast and allowed to harden for several days. They were then piled up by the derricks on both sides of the yard and stored for at least three months before being placed in the work. The yard averaged about 150 cubic yards of blocks in an 8-hour shift, 48 men working. The blocks on the upstream face are nearly rectangular, and being cast with a

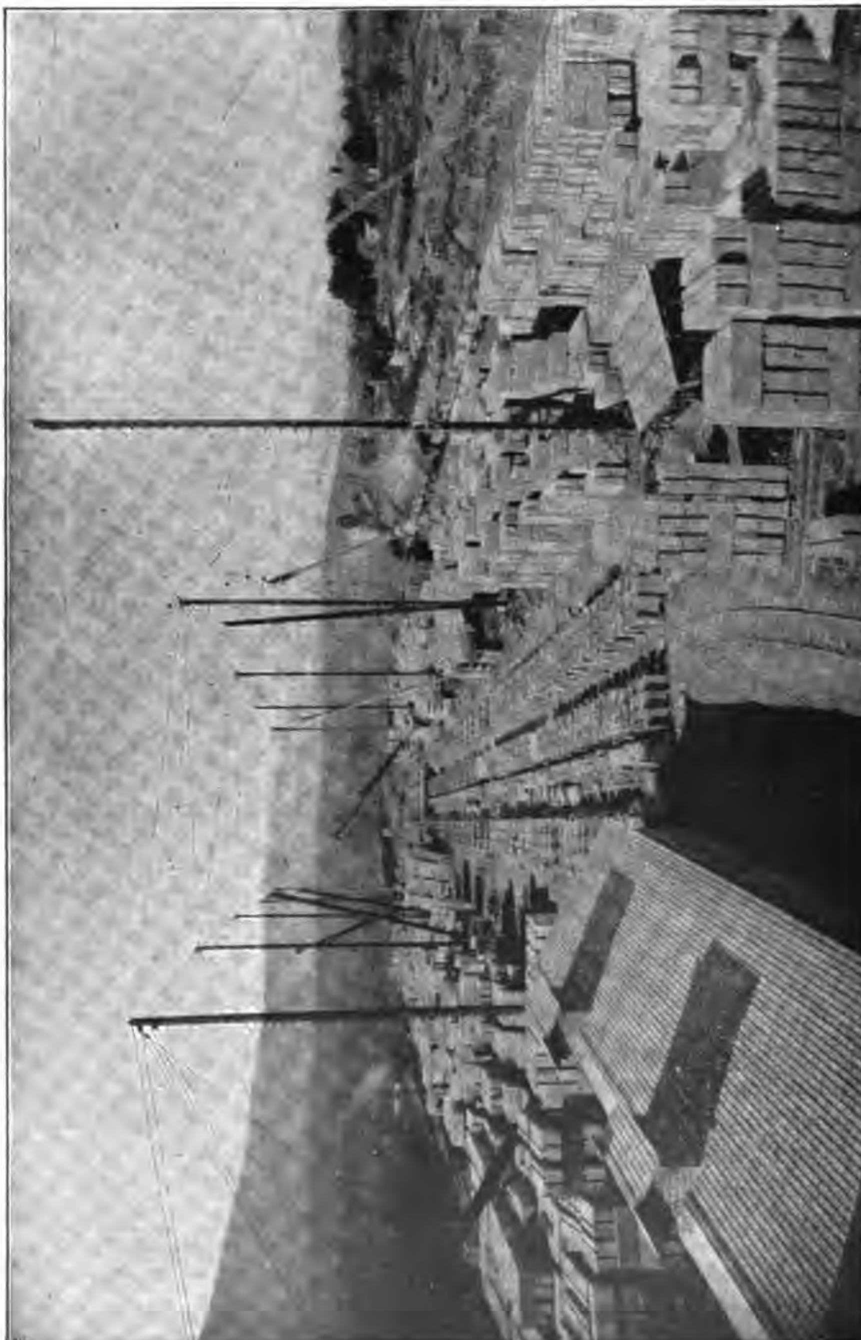


PLATE 38.—Olive Bridge Dam, Blockyard, Showing the Ten Derricks and Storage of Blocks for Dam. Blocks were Cast in Center from Traveling Platform over Form.

PLATE 39.—View of Blockyard at Olive Bridge Dam, Showing Forms and Derrick for Handling Blocks; also Traveler from which Forms were Filled.

liberal fillet on the exposed edges little trouble was experienced in obtaining perfect casting. Those on the downstream face have rather an acute angle, and some of them were broken by handling and in transportation. The contract allowed the broken blocks to be used in other portions of the masonry.

Main Quarry. Large quantities of rock were supplied by the deep cuts at the main gate chambers, the foundations of the dam itself, and various other points in the work. The Yale quarry on Acorn Hill was the main source of supply. This quarry has a vertical face of 1200 feet long and 30 to 40 feet high. A double-track spur from the contractor's railroad parallels the quarry face, and a row of 10 guy derricks served for handling the 5-yard steel skips from the quarry to the car. The cars were placed on one track for loading, and as they were loaded were taken out by the locomotives. The derricks, meanwhile, loaded trains on the other track, making the work continuous. The trains made the 3-mile trip to the dam with 10 cars in fifteen minutes, and back up grade with empties in twenty minutes. Three gangs of 12 men and 1 foreman each loaded the skips with the help of the derricks. The smaller stones were loaded separately into skips for the crushers, the larger ones being loaded by a derrick and used for the cyclopean masonry. The ledge is of bluestone of a hard and durable quality, but yields stone suitable for cyclopean masonry only in limited amounts. Like all the stone of this region, it tends to quarry into flat slabs with large beds and little rise, and of shape not favorable to a high percentage of large stone for the cyclopean masonry. Though an effort was made to place as many large stones as possible in the dam, on the total yardage of 426,000 they amount to only about 25 per cent. The face of the quarry was drilled in two lifts by Ingersoll-Rand air drills, the average daily output being about 800 cubic yards (Eng. Cont., Oct. 19, 1910). The holes were placed 6 to 8 feet apart, and the same distance back from the face of the quarry, the lifts varying from 16 to 22 feet. The holes were first sprung with from 1 to 5 sticks 40 per cent dynamite, and then loaded with from 1 to 2 kegs of black powder, tamped with dry clay. The firing was done by an electric battery.

Crushing Plant at Quarry. On the hillside below the quarry floor a crushing plant was installed, consisting of a No. 7½ and a No. 5 McCulley crusher, with a rated capacity of 70 yards per hour. The cars were loaded from the bins below this plant by gravity. An ingenious method of loading from a large storage pile was devised for this place. A spur track was surrounded by timbering, such as used in tunnels, and stone was deposited around it in a large pile. The cars were backed into this tunnel and loaded through chutes with little trouble. The crushing plant at the quarry served as an aid to the one at the dam, and supplied stone for various parts of the work.

Laying Up the Masonry Dam. The dam is composed of cyclopean masonry laid between walls of concrete blocks which acted as forms at the faces, and at the expansion joints. The cableways delivered the 3-yard Steubner bottom-dumping buckets to timber loading platforms, built either on or alongside the dam. From these landing platforms a 10-ton stiff-legged derrick with 60-foot boom lifted the buckets to the place where they were dumped by hand to form a bed for the large blocks of bluestone, varying in size from 1 to 10 tons. At the maximum there were about 16 derricks arranged in two rows. From elevation 500 upward advantage was taken of expansion joints, the derrick usually being located on alternate sections, which were built up considerably above the level of those adjoining. Below elevation 500, a section of concrete was built between walls which were carried up in advance of the body of masonry. These walls were racked back and consisted of large stones set close together embedded in concrete.

Use of Derricks at Dam. The derricks could be readily moved from place to place by the cableways. As the dam progressed up it narrowed in section, so that finally but one row of derricks could be worked, two of the cableways loading the platforms against the upstream and downstream faces of the dam. During the first season 8 gangs of men were employed with 16 derricks. During the second season 6 gangs of 8 men each were employed on the cyclopean masonry, but as the dam grew in height the proportion of this masonry decreased and the gangs were decreased. For setting concrete blocks an average of 7 gangs with 3 men each were used with a maximum of 10. In addition, 2 gangs were generally employed for one shift at night storing blocks and stone on the wall for use the following day. The total force employed at the masonry dam was about 156 men on day shift and 35 men at night.

Placing Cyclopean Masonry. The placing of cyclopean masonry, which is of utmost importance in dam construction, is here described in some detail. The first work was to clean old masonry or rock with wire brooms and water under pressure. Laitance was carefully removed from the hollows where at times it forms several inches thick. Next a thin cement grout wash was applied immediately before a batch of concrete was dumped

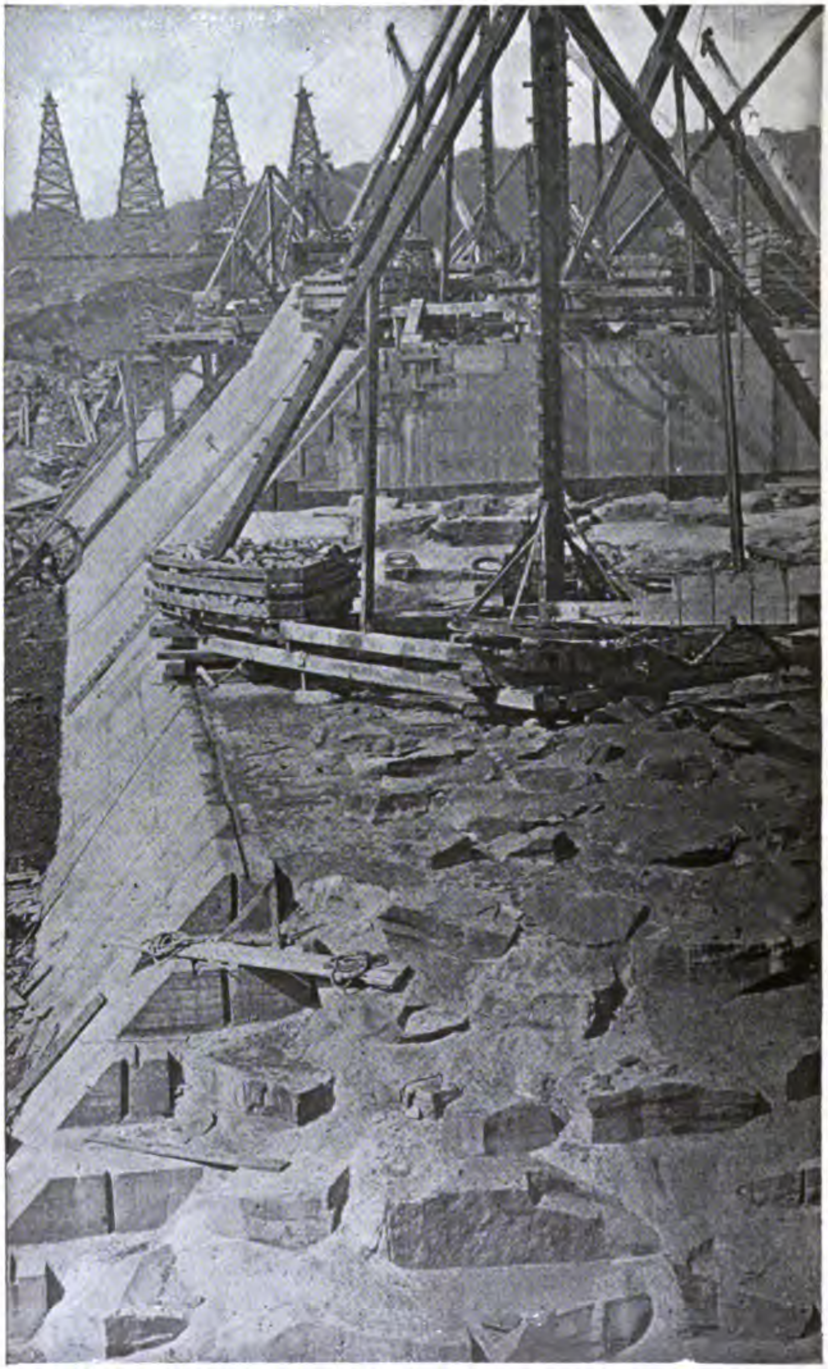


PLATE 40.—View of Partially Completed Olive Bridge Dam, Showing Concrete Facing Blocks, Cyclopean Masonry, Cableways, and Derricks Used in Placing Masonry; also Transverse Expansion Joint Across Dam.

and thoroughly broomed up to take up any loosened matter, securing a better bond between new and old work. Next a $2\frac{1}{2}$-yard batch of concrete 1 : 3 : 6 or 1 : $2\frac{1}{2}$: 5 was dumped on this prepared surface and spaded to remove air and to obtain an even distribution of the aggregate. Next the cyclopean stones, after being thoroughly cleaned and wetted down were lowered into place on the concrete by the stiff-legged derrick and well bedded by joggling with iron crowbars. Before being used each stone was carefully examined and those having seams were split and broken up in spalls. Very large stones were placed at least 2 feet apart and often required two or three batches of concrete for a bed, and when being joggled into place by four bars were partly supported by a derrick. The joggling continued until there was no indication of escaping air from underneath. The cyclopean stones were transported in steel skips by the cableway before being handled by the derricks. In a total yardage of 426,000 on the dam the cement ran one barrel per yard for cyclopean.

Concrete Block Setting. The concrete blocks were handled by the cableways and derricks the same as the cyclopean stone, except that they received much more careful treatment. The blocks were carefully set to break joints and well bedded in 1 : 2 mortar. The vertical joints were filled with liquid grout and later all face joints were raked out and pointed with 1 : 1 mortar. The blocks have grooves cast on the sides for dowel holds and to help bond them together. Owing to the great number of blocks in the dam, particularly at the upper portion, some difficulty was experienced in keeping the blocks laid ahead.

Concrete blocks make a clean-cut construction and greatly aid in concreting. Nevertheless, it would seem that a more economical method would be to use forms at all joints and surfaces not exposed to view. Well-designed and heavy steel forms used in panels supported by bolts in the masonry could be readily raised, and used repeatedly to form these surfaces, in which case the cyclopean masonry could be deposited directly against the forms with considerable saving. There is no doubt, however, that the concrete blocks give better appearing work than could be secured by forms. The cost of concrete blocks is ordinarily about one-half that of cut-stone masonry. Cyclopean masonry in turns costs less than half that of concrete blocks, although if considerable form work were required, this cost would certainly be much higher.

Very few forms were used on the main dam, the inspection galleries being about the only work requiring small forms. A temporary

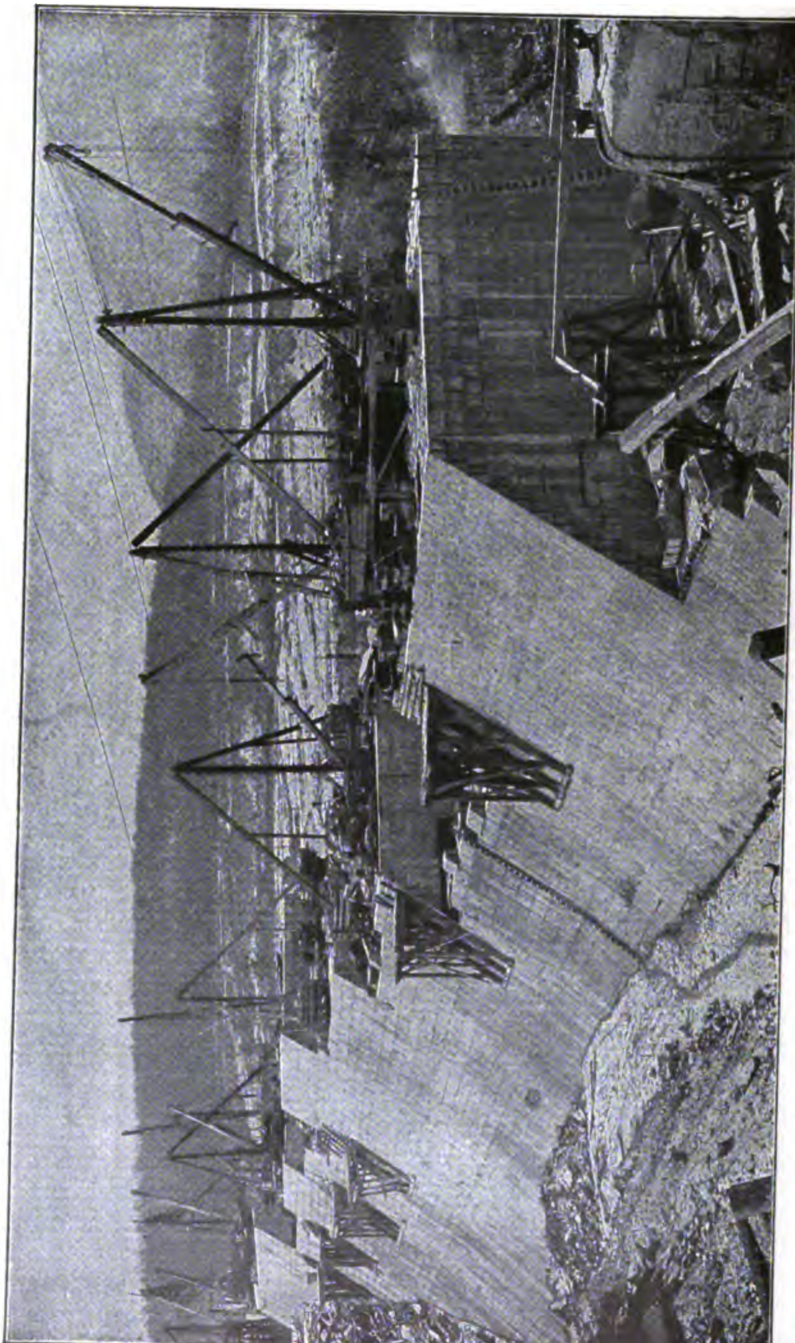


Plate 41.—Olive Bridge Dam. Masonry Section of Downstream Face, Showing how Dam was Built in Sections Bonded by Transverse Joints. Shows Derricks and Platform upon which the Cableways Delivered the Masonry.

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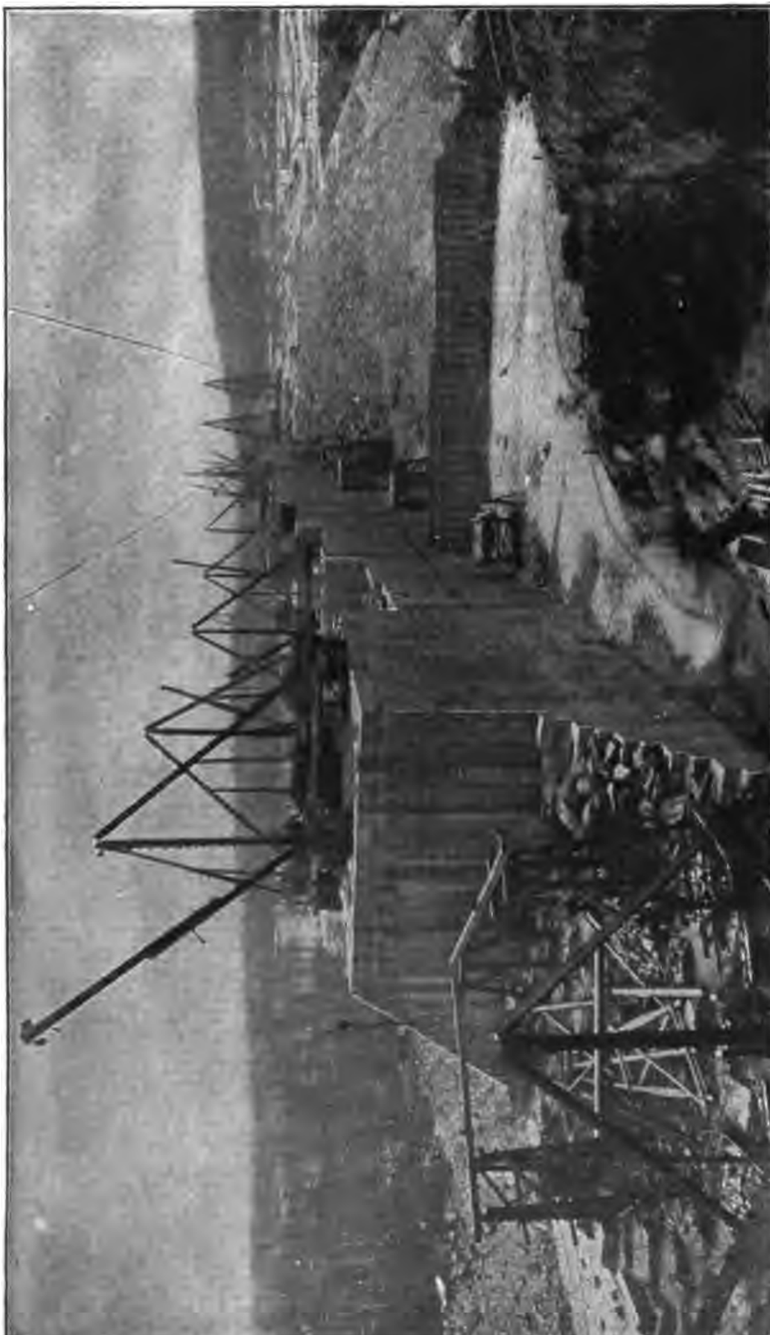


PLATE 42.—View of Construction of Olive Bridge Dam, Showing Derricks, Cableways, Cyclopean and Concrete Block Masonry, and Transverse Joint in Dam.

conduit for stream control was formed with the aid of 24-inch steel I-beams spanning the opening. These beams supported lagging on which concrete was placed, avoiding the use of false work which might be carried away by floods.

Records in Placing Masonry. It is believed that cyclopean masonry was deposited at a greater speed in this dam than, previously, at any other. During the month of October, 1909, 33,182 cubic yards of masonry were placed and 2117 cubic yards of concrete blocks were set in 29 days by 8 gangs per day. During 1909, 154,000 yards of cyclopean masonry, and 9000 yards of blocks were placed and set, and in 1910, 175,000 yards of cyclopean masonry and 27,000 yards of blocks set. The working season is about nine months. The last concrete block in the main dam was set March 2, 1911, so that in 27 working months, 426,000 cubic yards of cyclopean masonry, 7000 yards of mass concrete, and 56,000 yards of concrete blocks were set.

Earth Dams. The bulk of the work of Contract 3 consists in the building of earth dams or dikes. Each end of the Olive Bridge Dam terminates in a dike known as the north and south wing, the other dikes being the East, Middle and West Dikes. The entire area of the surface which the dikes cover was stripped of all soil and vegetable matter. Numerous boulders were moved to permanent positions at the toe of the slopes. A vertical trench along the center line was then excavated to rock, when within reasonable depths or to suitably compact hardpan. In trench a concrete core wall was built. The core wall is 4 feet wide on top, each face having a batter of 1 on 20.

Rolling of Embankments. The embankment was started by spreading layers of earth which were rolled to 4 inches on the water side and 6 inches on the dry side of the core wall. These layers were rolled with 12-ton Monarch and Kelly steam-grooved rollers of a special design of unusually high horse-power for their weight. Prior to dumping the material for a new layer, the surface was sprinkled with water, and the roller then traveled back and forth, lapping over one-quarter to one-sixth of its width. Occasionally cross rolling was required.

Core Walls. The core wall was usually built in courses 6 feet high and 75 to 150 feet long corresponding to the amount of concrete which could be placed in a single 8-hour day. The cantilever form used in building a greater part of the core walls is shown on Plate 44. This form proved its great efficiency on miles of core walls and is applicable to wide range of similar work, such as retaining walls.

PLATE 43—View of Upstream Face of Olive Bridge Dam during Construction. Spring Freshet Passing through Culvert in Dam.

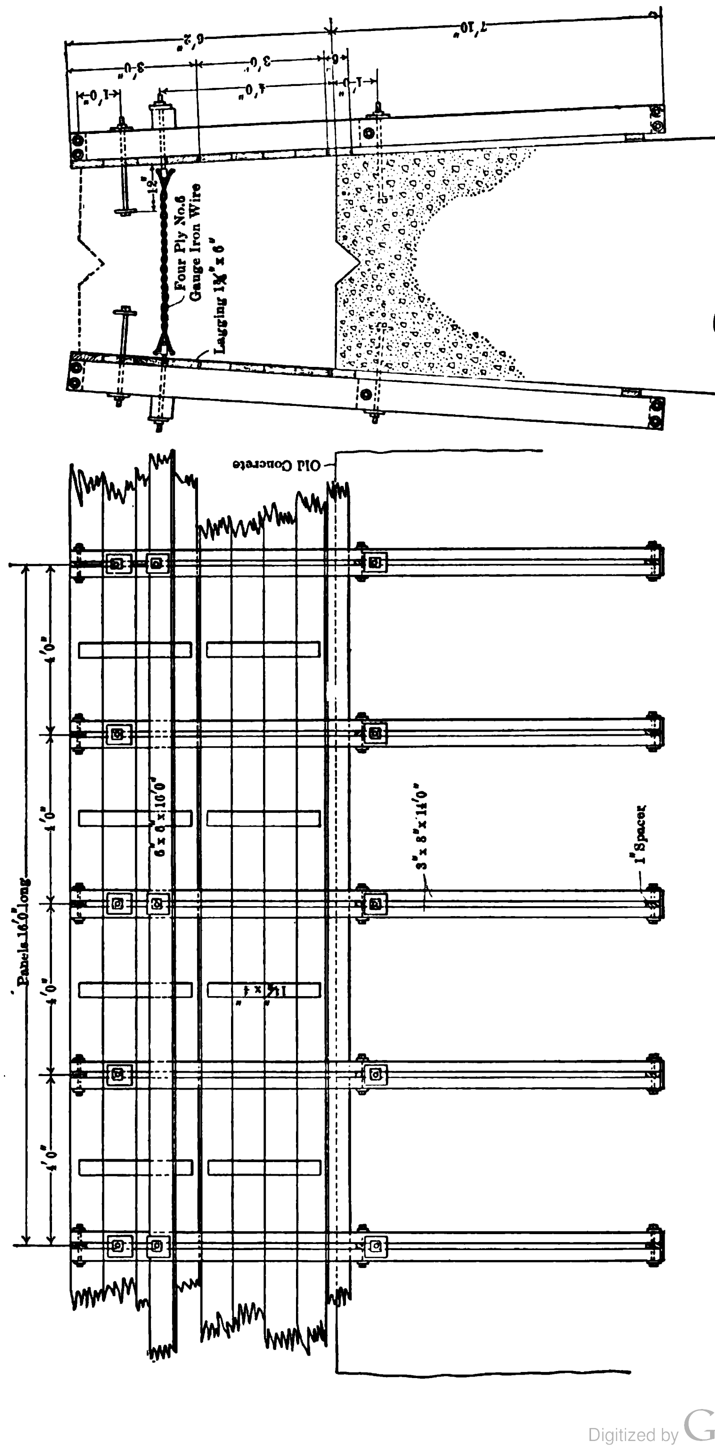


PLATE 44.—Details of Construction of Cantilever Form for Core Walls at Ashokan Reservoir. Method of Fastening and Using Forms.

It is simply constructed of pairs of vertical 3″×8″×14′ timbers spaced 1 inch apart, the pairs being 4 feet center to center. For the top 6½ feet horizontal 1¼″×6″ lagging was nailed. The verticals are held in position by bolts embedded in concrete and by wires twisted so as to give the required width of wall. In each 6-foot lift a pair of bolts is concreted, after which the form is moved upward, the bolts fitting in the slot between the 3″×8″ uprights. The form is lined up by wedging the projecting lower ends of verticals against the concrete and by twisting the wire spacers.

South Wing. The surface was stripped by hand work, using wagons drawn by mules. The trench for the core wall was excavated with a Page excavator. Due to the numerous boulders encountered this machine could not work with advantage and later was converted into a derrick and used to convey buckets and skips in the ordinary manner. For the concrete work a quarry was opened on the hill above the work about 1000 feet from the concreting plant at the south end of the dike. The stone from the quarry was brought to a No. 5 Gates crusher at the mixer in 3-yard side-dump cars on a narrow-gauge track. Crushed stone was drawn from the bins directly into a 1-yard Ransome mixer. Sand was brought from the main pit by the railroad and cableway and hauled by bottom-dump wagons to storage pile at mixer. The concrete was conveyed in 1¼ cubic-yard Steubner buckets on a narrow-gauge flat car run by gravity. A traveling derrick deposited the concrete in the forms.

Building Embankment. For building the embankment a 70-ton Bucyrus steam shovel loaded 4-yard dump cars which were hauled, in two trains of 12 cars each, over a narrow-gauge track to the embankment. The earth after being dumped from the tracks was spread by hand in layers and the stones culled out and hauled on stone boats by mules to the Class C embankments, and placed at once on the completed slope. The track was thrown by hand as often as necessary to build out the layers. To loosen the material in the borrow pit so as to be readily handled, a Star well-digging machine was used, holes being sprung and blasted in the usual manner. On the south wing the average output under favorable conditions of the mixing plant was 100 cubic yards in eight hours, and about 900 cubic yards of embankment per day were placed. About 2 miles of narrow-gauge track was placed. In addition to the equipment before described, 40 mules and dump wagons were used for hauling. A typical working gang was, borrow pit crew, 10 men; two train crews of 4 men each; a track gang of 19 men, and a spreading gang of 40 men. The south wing was built by Johnson & Briggs.

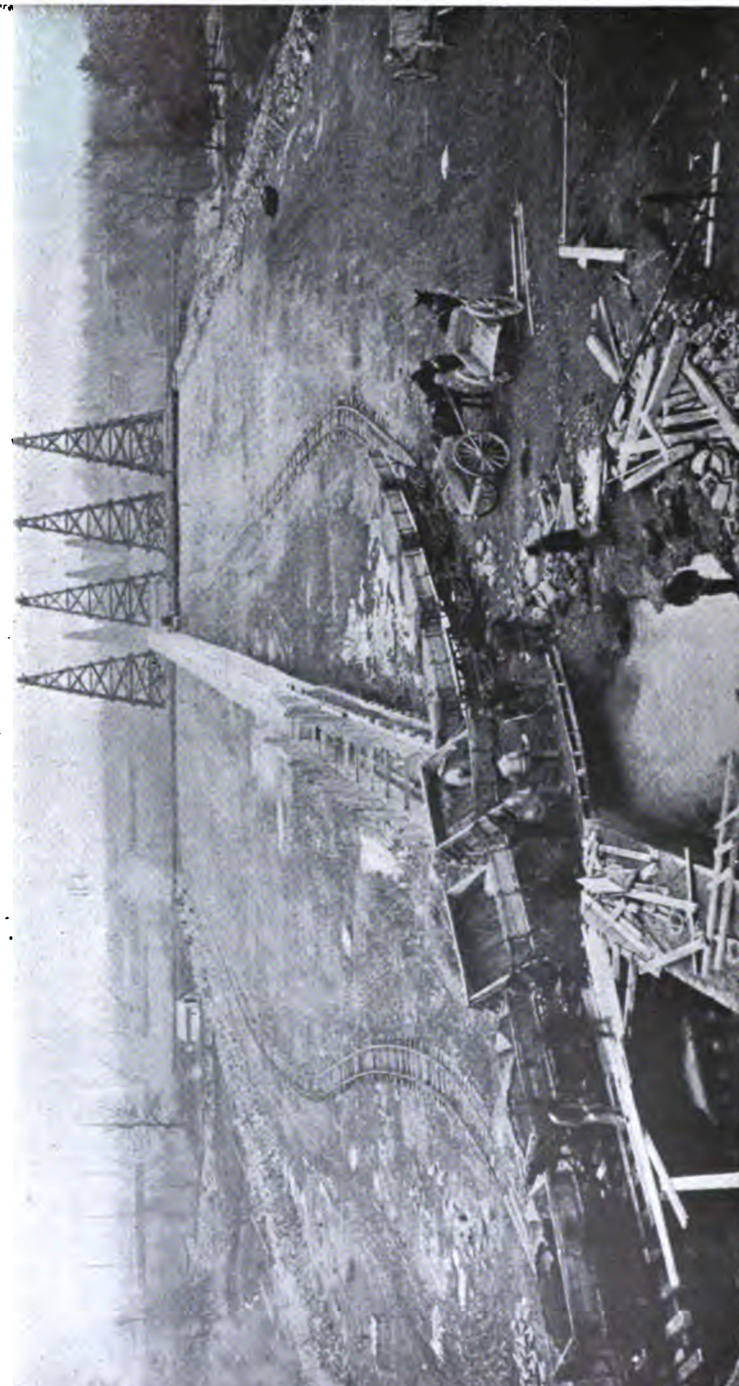


PLATE 45.—Olive Bridge Dam, South Wing. Building of Impervious Embankment. Glacial "Hard-pan" Dumped from Trains and Rolled to 4-inch Layer Upstream Side and 6-inch Layer Downstream. Constructed to Lines Shown on Plate 32. Boulders in Fill Used for Riprapped Slope.

North Wing of Main Dam. The soil was stripped in the same manner as for the south wing, and excavation for the core wall made with traveling derricks. The concrete was mixed in a 2½-yard cubical mixer which discharged into a Steubner bucket, and was placed in the forms by traveling derricks. Material for the concrete was brought by carload trains from the main crusher, sandpit and cement house. Material for the embankment was brought from the Winchell borrow pits in three trains of 9 to 11 4-yard Western dump cars hauled by 20-ton American dinkies. The borrow pit was excavated by a 70-ton Bucyrus steam shovel with a 2½-yard dipper. The haul from the borrow pit was about a mile, and the daily progress was 1000 cubic yards in eight hours under favorable weather conditions. The material from this borrow pit contained many boulders which were hauled in stone boats to the slopes of the embankment, this being the general rule on this work.

Typical gangs on the embankment were, borrow pit force, 13 men; trains, 11 men; track work, 23 men; spreading gang, 53 men. The typical gang for the core wall was: erecting form, 7 men; mixer, 18 men; hauling and placing, 14 men; the average output being 150 cubic yards in eight hours.

West Dike. This is located just east of Winchell Hill, and is about 1800 feet long. After the soil had been removed in the usual way, the core wall trench was excavated with a Page excavator and traveling derricks. Adjoining Winchell Hill, 2 to 10 feet of disintegrated rock were removed in the foundation for this wall. A traveling cableway similar to those at the main dam of 1534-foot span was installed here, and handled part of the excavation and the concrete, also the earth for building the embankment on each side of the core wall.

Concrete Plant. A mixing plant of large capacity and unique construction was installed. Two tracks of the contractor's railroad were led over large stone and sand piles. Under these piles a timber tunnel with chutes opening into the sand and stone was built. In this tunnel, a large link belt conveyor was installed, the buckets of the conveyor being fed from the chutes and discharging at a considerable elevation into the sand and stone bins which in turn discharged into measuring hoppers, feeding a 2½-yard cubical mixer. This in turn discharged into bottom dumping buckets on flat cars drawn to the cableways supplying the core walls.

Making Embankments with Mule Teams. It was found that with sixteen 1¼-cubic yard capacity wagons drawn by teams of three mules a distance of about 1000 yards over fair roads, an average of

PLATE 46.—View of Construction of North Wing of Olive Bridge Dam, Showing Core Wall, Cableways, for Dam, Making of Embankment, etc.

280 loads or 420 cubic yards of embankment could be hauled in eight hours. However, a greater part of the material was delivered in 6-yard skips from standard flat cars hauled in trains of from 10 to 13 cars each, from the westerly end of the West channel, and dumped into position by cableway. Due to height of drop the material compacted and had to be loosened by plowing before it could be spread and rolled. About 1000 cubic yards under favorable conditions were placed in eight hours.

The Middle Dikes. This is 7100 feet long, extending from the west dike easterly to Leonard Hill. The construction was carried on in three sections, viz., the west, 2200 feet long; the center, 2350; and east, 2550.

West Portion of Middle Dike. Clearing and stripping was done as before described; excavation for core walls was taken out by hand, good rock being found from 2 to 8 feet down. The first concrete done was with a small portable mixer which discharged into wheelbarrows which placed the concrete in the forms. Embankment material was hauled in Western side-dump cars from the Winchell Hill borrow pits on tracks running over top of core wall; material dumped to either side was spread by two-mule drag scrapers. The material was similarly hauled from the central part of the west channel excavation, but dumped directly into place on the embankment.

Comparative Advantages of Building Embankments by Dumping from Wagons and from Trains. Generally the most economical and satisfactory method is to haul directly to the embankment, dumping from tracks thrown by hand. The making of embankments by hauling in bottom-dumping wagons and spreading by hand and then rolling gives probably the best results, the wagons giving a rolling additional to that of the steam rollers, though it is not nearly so economical for the contractor as hauling over tracks.

Center Portion of Middle Dike. This dike, the highest and most important, crosses Beaverkill Creek, which was diverted into a $14' \times 9'$ concrete conduit 600 feet long. Most of the core-wall trenches were 10 to 15 feet deep, excavated by hand.

Excavation of Preglacial Gorge of the Beaverkill. During the first season, 1908, the excavation in the preglacial gorge of the Beaverkill was handled by two Page excavators. These machines formed slopes of about 1 on 1 and loaded into wagons, through hoppers, the material being then used in embankments. Many large boulders which required considerable blasting delayed the excavation, which proceeded at the rate of 400 to 600 cubic

PLATE 47.—View of Core Wall for Beaverkill Dike, Cantilever Forms, and Cableway Used for Placing Concrete, etc.

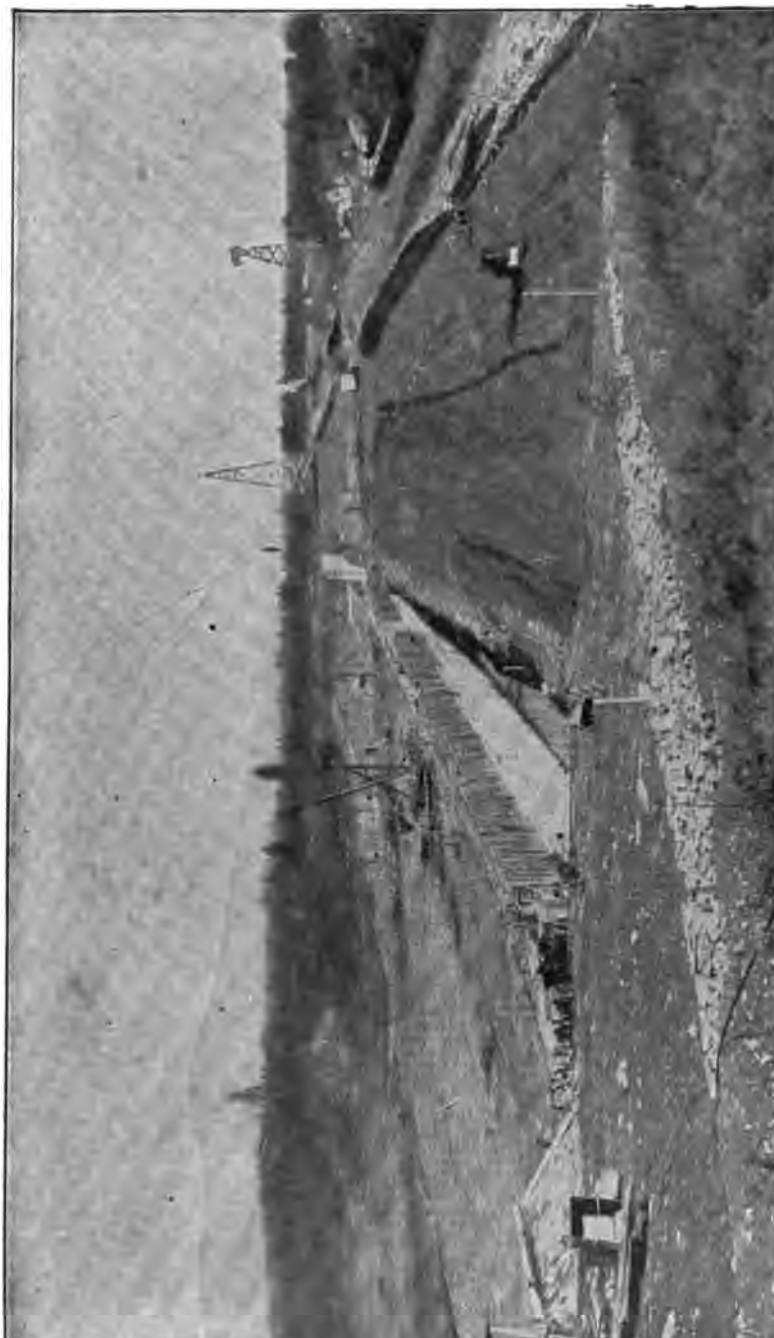


PLATE 48.—General View of Beaverkill Dikes. Gap in Core Wall Left for U. & D. R.R. Building of Embankment.

yards per eight hours for both excavators. The excavation by Page bucket was economical within reach of the swing of the boom for a depth of about 30 feet. Part of the time the buckets were hauled to the further limits of the excavation by wire cable and auxiliary engine on the opposite side of the gorge. This increased considerably the radius of action of the machine. The material was so hard and dry that considerable of it was drilled by ordinary percussion drills and blasted to loosen up the hardpan for the Page buckets. When wet the material ran out of the bucket about as fast as it filled.

Construction in Beaverkill Gorge. During the second year, 1909, the Beaverkill gorge was spanned by a cableway which rapidly removed the material to a depth of about 80 feet, the Page excavator having previously worked to a depth of 30 to 40 feet. The preglacial gorge was fully exposed and found to be very symmetrically stepped from the top width of 150 feet to the bottom width of 40 feet, a depth of 80 to 90 feet. The bottom was at elevation 422, or 165 feet below the water surface of the East Basin. The floor of the gorge was found to be sound rock and little excavation was necessary at the sides which were composed of alternating layers of bluestone and shale. The material near the bottom of the gorge was found to be sand, gravel and boulders with some clay. From the borings it was anticipated that this would be wet, although little water was encountered in the excavation. To guard against loss of water through this buried channel an arched core wall 30 feet thick was built in the gap and the remainder of the excavation refilled with compact material which was dumped from skips by the cableway into a water puddle. At this point the embankment for the Middle Dike will have a maximum height of 115 feet above the original surface of the ground, and about 185 feet above the bottom of the preglacial gorge.

Easterly Portion of Middle Dike. This section was done by Newel & Snowling Construction Co. & N. S. Brock. Clearing, stripping and excavation for the core wall were done by hand. The core wall was concreted in 6-foot lifts and the embankment carried up to the top of the wall before the new lift was placed. This method allowed the use of a minimum amount of plant and was very economical. The core-wall concrete was mixed in a 1-yard portable Municipal mixer, discharging into bottom-dump buckets which were lifted and dumped into place by a traveling derrick alongside the core wall opposite the concrete plant. The cement and sand were supplied by the main contractor and hauled by teams to the

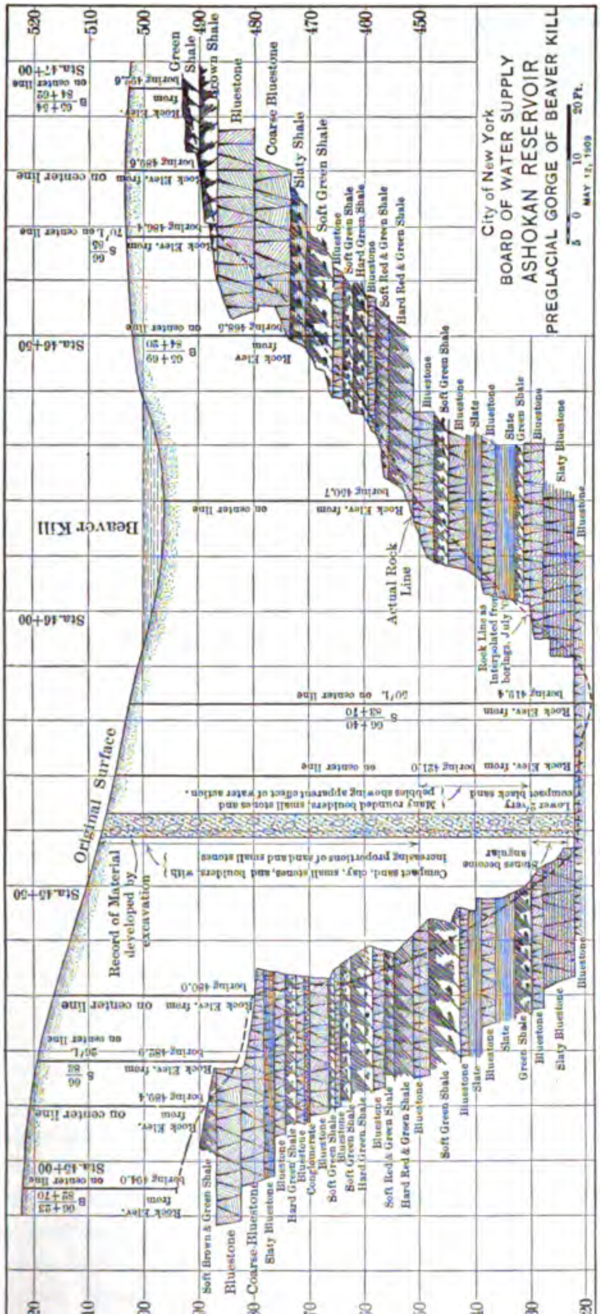


PLATE 49.—Preglacial Gorge of the Beaverkill. Comparison of Cross-section as Determined by Borings with that Actually Exposed by the Excavation. Shows Stratification of Bluestone and Shales.

mixer. Crushed stone was obtained from a No. 5 Austin crusher supplied by field stone. The bins were emptied into carts measured for one batch, which in turn dumped into the discharging hopper of a mixer. Embanking material was obtained from Temple Hill. Side-dumping cars loaded by a steam shovel were hauled directly onto the bank and dumped, the tracks being thrown and the material spread by hand. About 1200 cubic yards of embankment were made per day.

East Dike. The East Dike is 3600 feet long and was constructed by Johnson & Briggs. It is at the extreme eastern end of the dikes, extending from Leonard Hill to the Waste Weir. Stripping was done with pick and shovel and cars, the material being deposited in spoil banks to be later used in surface dressing. The excavation for the core wall, varying from 4 to 10 feet, was made by hand. This dike crosses a small swamp, necessitating an excavation from 1 to 5 feet in depth.

The core wall had a maximum height of 30 feet, was built in two lifts, using wooden forms braced against the ground. Sand and cement were teamed from Brown's Station. At first, crushed field stone was used,afterwards stone from the Waste Weir excavation and from a small quarry. The mixing and crushing plant situated at the junction of the dike and waste weir consisted of a No. 5 Gates crusher, elevated sand and stone bins, a guyed derrick with 60-foot boom and a Municipal cube mixer. This mixer was later moved to the center of the dike for concreting the west half.

Building Embankment for East Dike. The major part of the embankment was built after the core wall was finished. From Stewart Hill borrow pit a narrow-gauge track was run over the top of the core wall, the material brought in side-dump cars and dumped to either side of core wall, spread by drag scrapers and rolled as usual. About 300 cubic yards per day was usually placed. The 4-yard cars were loaded by a 20-ton Thew steam shovel with $1\frac{3}{4}$-yard dipper. The average force for the 8-hour shift worked was, borrow pit, 9 men; trains, 7 men; on embankment, 27 men. Later a 70-ton Vulcan shovel was used.

Waste Weir. The Waste Weir, about 1000 feet long, was constructed by Johnson & Briggs. Much heavier construction was used than originally contemplated, as a thick cover of disintegrated rock was found. Earth excavation was by pick and shovel and removed in bottom-dump wagons. The rock was drilled by Ingersoll-Rand drills, shot with 40 per cent dynamite and loaded by a Vulcan steam shovel into skips on flat cars or into bottom-dump wagons. Compressed air was supplied by a 6-drill Ingersoll-Rand compressor. A cut-off trench about 6 feet wide and 4 to 6 feet deep was excavated the entire length of the waste weir on the upstream side.

The design of the waste weir is shown in plan and cross-section on Plates 50 and 51.

Masonry for Waste Weir. This weir is built entirely of cyclopean masonry and has a maximum height of 11 feet. The crushing plant was that described for the East Dike and a 1-yard Ransome mixer was located near by. The concrete was discharged in 1-yard Stuebner bottom-dump buckets placed on flat cars and run by gravity on narrow-gauge track to the forms where they were placed by a traveling derrick. The forms were built of wood, braced against the ground or finished masonry, which was carried up in steps about 2 to 5 feet high, the full thickness of the weir, and for a length of 25 to 40 feet between expansion joints. The surface of the concrete at the end of a day's work was sloped toward the upstream side with large cyclopean blocks projecting to make a bond for the next lift. A good deal of the sand was artificially made by a small stone jaw crusher feeding into a pair of Sturtevant sand rolls. The stone was quarried near by and delivered to crusher in steel skips on flat cars. Downstream from the Waste Weir, the rock, being soft, was excavated to a depth of 18 inches with light charges of powder, also by barring and pick and shovel, and was replaced by a concrete floor built in alternate blocks 7 feet square. The concrete was delivered to this floor in Koppel side-dump cars running on narrow-gauge track.

West Channel. This cut was necessary to make the upper 100 feet of the reservoir available, the gate chamber being located in rather high ground. About 1,000,000 cubic yards of excavation will be removed, practically all earth and acceptable material to be used for Class A or B rolled embankment. The cut begins at the Esopus about 6000 feet from the gate chamber. At this point a 70-ton Atlantic steam shovel with 2½-yard dipper loaded 5-yard skips on flat cars, 12 to a train. Trains were hauled to the west end of the West Dike where a cableway dumped the skips into place. About 1000 cubic yards per day were removed at this point under favorable conditions. At a second point about the middle of the channel another 70-ton shovel loaded into Western side-dumping cars which were hauled over narrow-gauge track to the westerly edge of the middle dike, the shovel averaging in good weather about 1000 yards per day of eight hours.

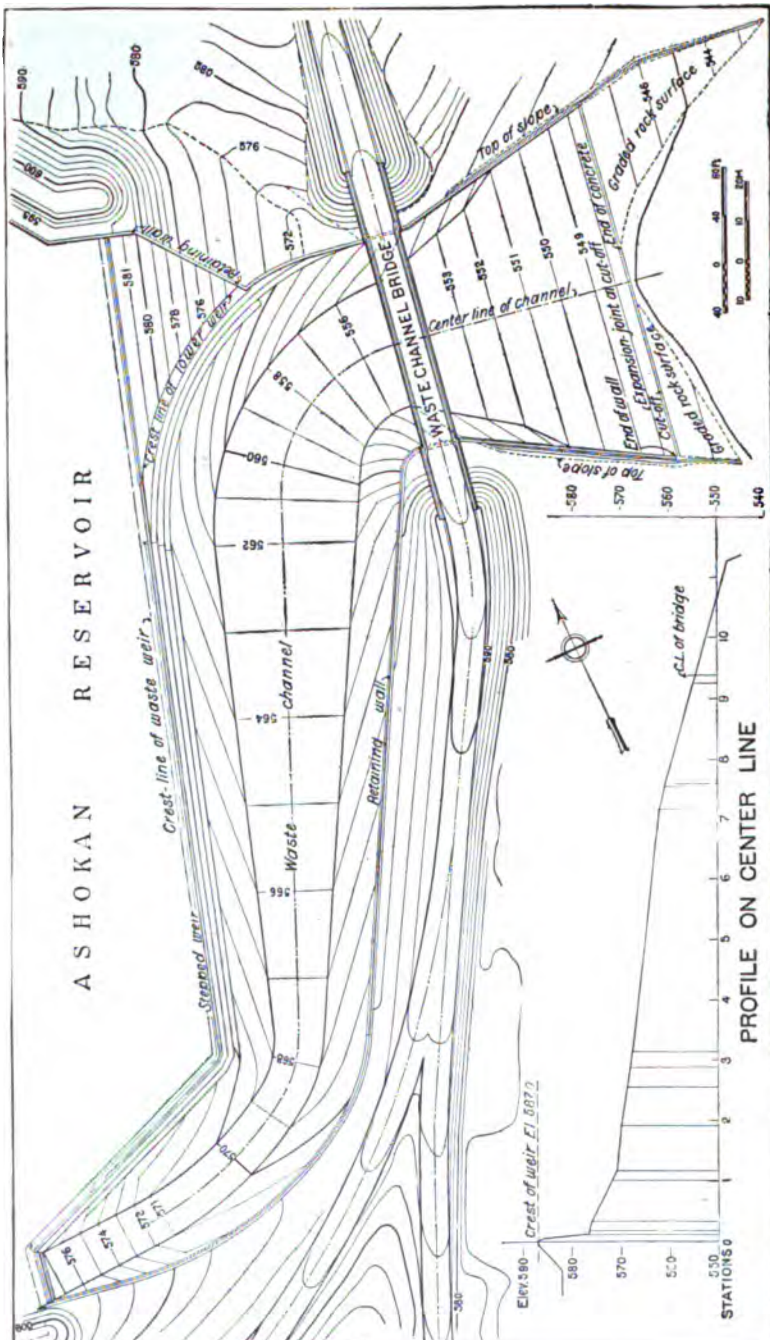


Plate 50.—Contour Plan and Profile of Waste Channel for Ashokan Reservoir.

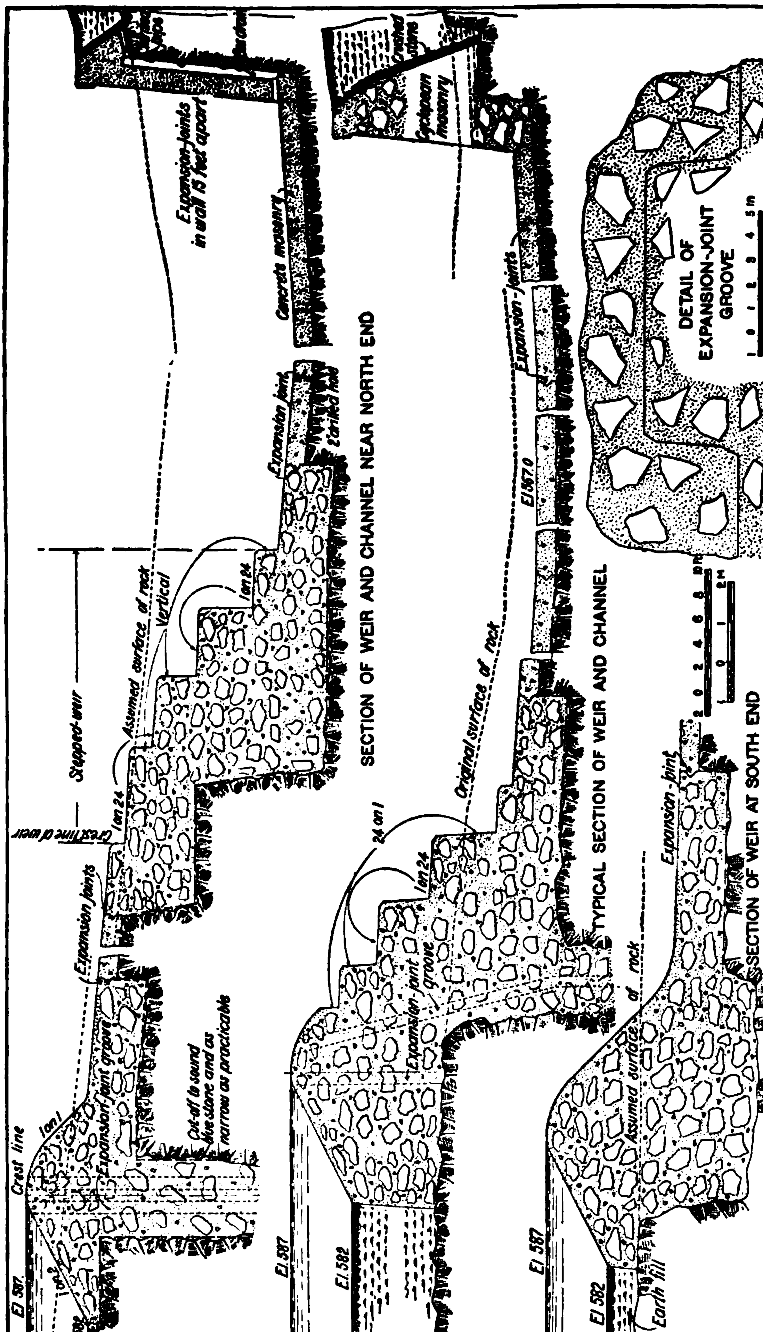


PLATE 51.—Waste Weir at Ashokan Reservoir. Typical Cross-sections.

East Channel. In this channel, which was chiefly in rock extending from the upper gate chamber to the Beaverkill, the earth cover varied from 2 to 10 feet with a few deep pockets. This was mostly removed by pick and shovel and three-mule bottom-dump Western wagons. For about 400 feet a 30-ton steam shovel loaded directly into wagons. The excavated earth was used to make fill for a railroad along the south side of channel. For the rock excavation 4 gangs of 25 men each were used, each gang excavating about 100 yards per eight-hour day. At each point two Ingersoll-Rand air drills were used, drilling holes from 8 to 12 feet in depth. To define the lines of the channel the holes were placed 2 feet apart, otherwise 5 feet on centers. No great precautions were taken to prevent overbreaking, as all rock excavated was used at the crusher or for making rock fill below the main dam. Four traveling derricks with 60-foot booms were used to raise the muck in 4-yard skips to flat cars operating on standard-gauge track. The excavation of the East channel supplied great quantities of stone for cyclopean masonry and concrete; during a portion of 1911 the rock supply was sufficient so that the Yale quarry was shut down.

Gate Chamber. A great excavation was necessary at the upper gate chamber, at the junction of the east and west channels. Sullivan channelers were used in this excavation to define the sides of the rock cut to a depth of about 6 feet, after which Ingersoll-Rand percussion drills were used, spacing line holes at 6 inches apart and using light charges. The excavated rock was moved by derrick and cableway.

Cut for Pressure Aqueducts. Leading from the gate chamber a great rock cut was made for the purpose of building in it two pressure aqueducts. This trench was very carefully excavated, using Sullivan channelers for the side, the central portion being drilled and lightly shot, and the rock removed by cableway. The maximum depth of this cut was 65 feet. In this way a remarkably clear-cut work was obtained, the sides being smooth and not presenting the usual broken appearance. The excavation was taken out in 6-foot lifts, the channelers setting in 9 inches at each lift. Each channeler was able to do about 45 square feet of surface in eight hours.

Wooden forms were used for the aqueduct at the bottom of trench, the concrete being placed directly by the cableway. The filling of this trench above the aqueduct offered an excellent opportunity to run a concrete plant at its maximum capacity, the plant placing at a maximum 610 yards of concrete in eight hours.

PLATE 52.—View of Trench Channeled in Bluestone and Shale for Pressure Aqueducts, just before Placing Concrete. Cableway Used for Removing Excavation, etc.

CONTRACT 10

Headworks of Catskill Aqueduct at Ashokan Reservoir. This contract was awarded Dec. 1, 1909, to Jules Breuchaud, for a total of $1,146,600. The principal items are:

Earth excavation,	per cu.yd...........	$0.68	
Rock excavation,	"	2.50	
Refilling and embanking,	"	.20 and 0.60 for	2,000 yds.
Concrete masonry,	"	5.80	" 165,000 "
Reinforced concrete Masonry,	"	8.00	
Portland cement,	per barrel...........	1.50	

This contract has a length of 4300 feet, of which 840 feet is special aqueduct, screen chamber and lower chamber aqueduct, and 3460 feet cut and cover. With the exception of the cover-and-cover, work on this contract is very special and extremely complicated. Mr. Breuchaud was also connected with the contract for Ashokan dams, so that Contract 10 was carried out in conjunction with Contract 3, from which material, plant, equipment and men were freely drawn.

Excavation. Earth excavation in the open cut was made as follows: Upper portion was removed by the steam shovel, wheel scrapers, and also by hand. The earth trimmed just in advance of the invert was shoveled into skips and removed by derricks. The invert was constructed in the usual way.

Wooden Forms for Cut and Cover. This contract was unique in that it is the only one on which wooden forms were successfully used for concreting full-size cut-and-cover aqueduct. The side forms were built in two parts, the lower form allowing the concrete in the side walls to be raised to an elevation of 8 feet above invert. These forms were set on the invert, heavily braced transversely, the wooden lagging being covered with 23-gauge galvanized metal. The forms for the arch were set on the invert after the side-wall forms were moved ahead. They were heavily trussed and braced. The outside forms were also wood, supported by bolts placed in the concrete of the side wall and invert. Excellent work was obtained with these forms, but as the concreting was started in two or three places and a stretch of only 3000 feet was constructed, they were not used over again many times. Toward the end they showed signs of distortion, so that it is probable they would have had to be renewed or remade for a longer stretch of aqueduct. Derricks were erected alongside the cut and were used to place concrete and remove the

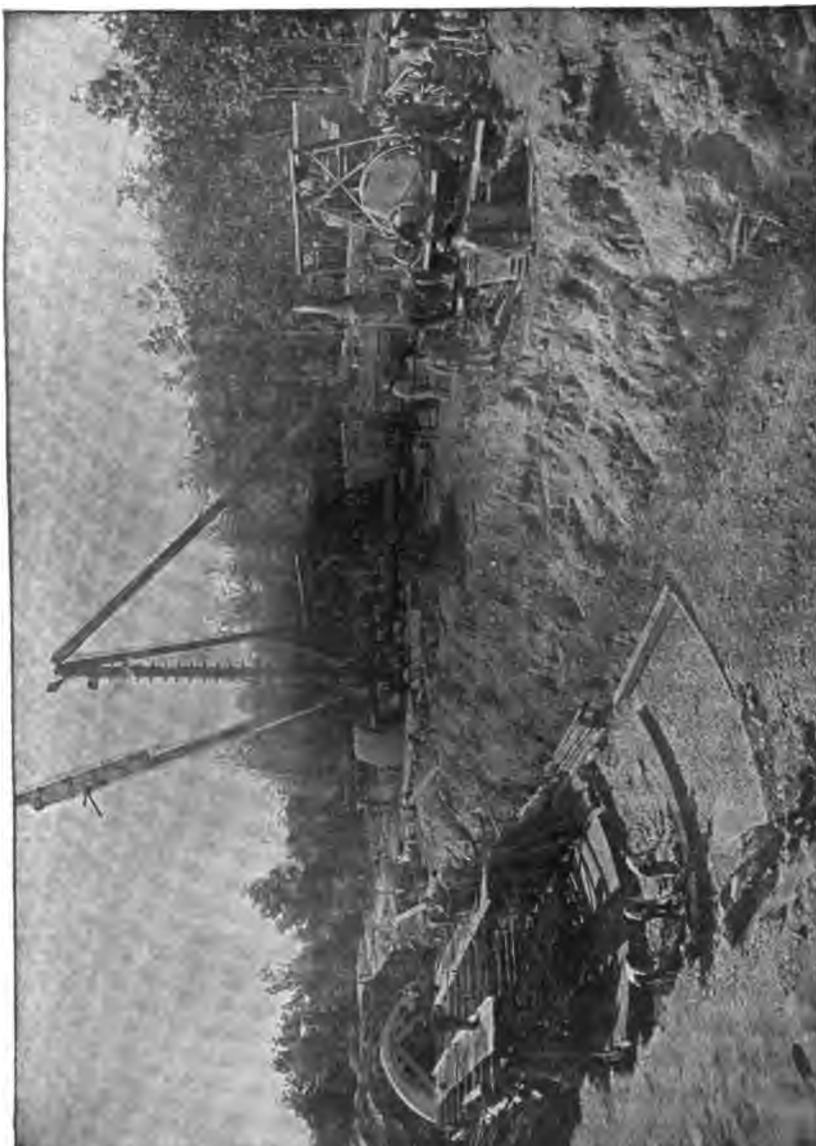


PLATE 53.—Construction of Cut-and-cover Aqueduct, Contract 10, Showing Wooden Forms and Derricks for Moving them, Placing Concrete, etc.

wooden forms. Concrete was mixed in small portable mixers to which material was brought in carts from the main dam. Although the first cost of the wooden forms is probably less, it does not appear to the writer that they are as economical as steel forms, as they cannot be taken down and erected as rapidly, or used over and over for an indefinite number of times.

Contract 60

Hurley Dikes, Work and Prices. This contract was awarded in December, 1909, to McArthur Bros., for the total contract price of $971,000. Under it, the Glenford, Woodstock and West Hurley dikes, 1.6 miles long, were constructed. These dikes close gaps at the eastern end of the East Basin. The main prices are

Earth excavation,	per cu.yd.	$1.40
Rock excavation,	"	3.00
Refilling and embankment,	"	.50
Concrete masonry,	"	4.75
Portland cement,	per barrel	1.40

Construction of Embankments. The construction of core walls and embankment was similar to that described under Contract 3. In the borrow pits three steam shovels ranging from 70 to 20 tons were used. To transport the material for earth embankments about 4½ miles of narrow-gauge road were built upon which were operated trains hauled by 12- to 18-ton locomotives, hauling 3- to 4-yard dump cars. The material from the borrow pits after being dumped from cars was hauled to place by slip scrapers and compacted by special 13-ton Monarch roller, the boulders being hauled to one side. For the wider part of this embankment the earth was deposited directly into place by narrow-gauge trains, the tracks on the dikes being thrown as each layer of embankment advanced across the fill. An excellent view of the construction of the Woodstock dike is shown on Plate 54.

Core Walls. A core wall 1835 feet long for the Glenford dike was founded on rock, the depth from the surface to rock varying up to 30 feet. The core-wall trench was excavated with vertical sides in compact material. The Woodstock dike was built in a similar manner, the material being obtained from the borrow pit 3000 feet distant. When the embankment became too narrow to accommodate narrow-gauge tracks a single track was placed on the core wall from which, after being dumped, the material was distributed by slip scrapers.

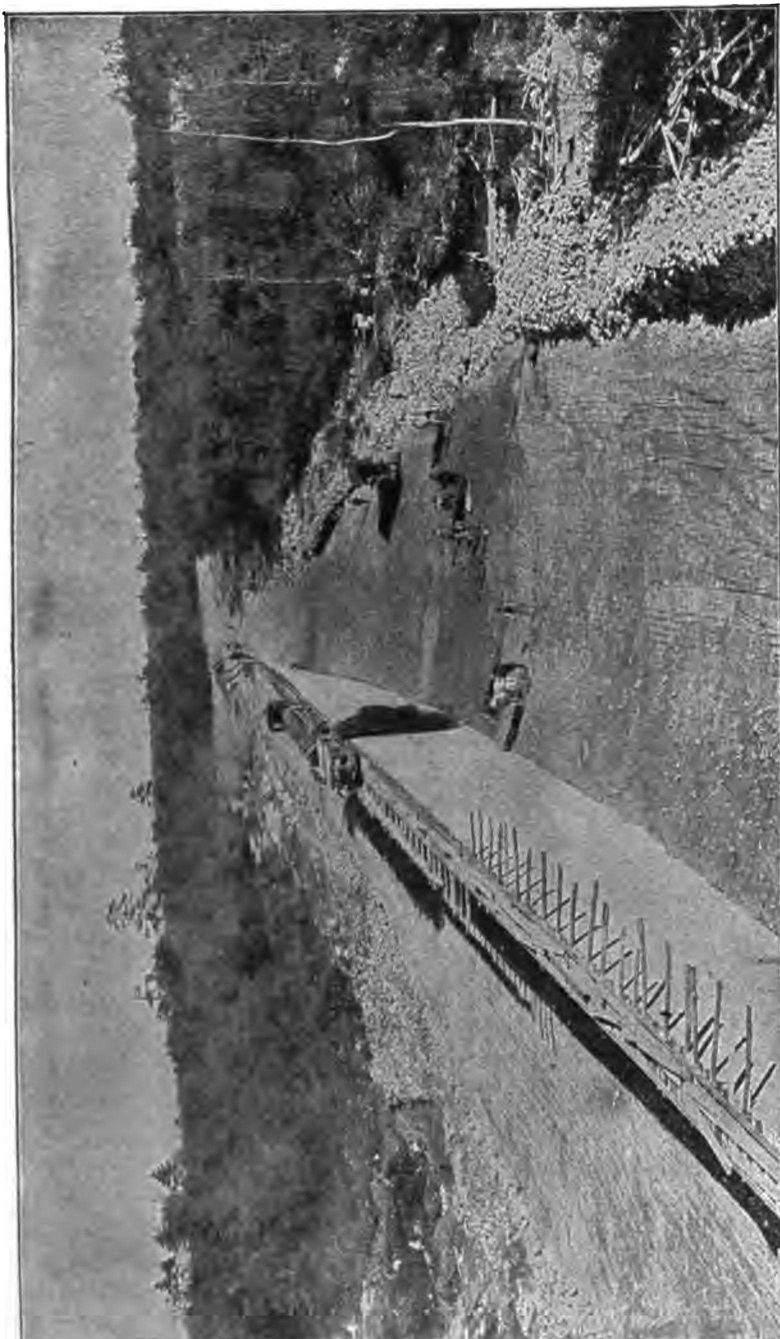


PLATE 54.—Ashokan Reservoir. Woodstock Dike, Closing Gap at East End of Basin. Train on Core Wall Dumping Embankment Material.

Concreting of Core Wall. To concrete the core walls small stationary mixing plants of ½-yard capacity were arranged with bins to receive crushed stone and sand, the stone being supplied from small crushers fed with loose stone from adjacent quarries. The concrete was delivered to the core walls in small steel dump cars which discharged into the trench while the core wall was below ground. Above the ground the forms were built in panels about 6 feet high and concrete cars run on top of them. During 1910 about 31,000 cubic yards of concrete were placed, the maximum for one month being 7410, about 290,000 cubic yards of embankment being placed in the same year, the maximum for any month being 58,000.

CONTRACTS 5 AND 48.

Kingston Sewer. By legislative enactment the City of New York was required to divert that portion of the sewage of the City of Kingston emptying into Esopus Creek to another outlet, for the reason that after the completion of the Ashokan Reservoir insufficient water would flow in Esopus Creek to properly carry away sewage. The main outlet sewer was diverted to Rondout Creek by the construction of 6200 feet of 24-inch pipe sewer, and 6200 feet of sewer tunnel; 4900 feet of the 24-inch pipe was laid under Contract 5 by the Haggerty Construction Co., the remainder under Contract 48 by King, Rice & Ganey Co.

Sewer Tunnel. The sewer tunnel was built to avoid a deep cut and to contain the pipe sewer. It was constructed from four shafts, ranging in depth from 21 to 94 feet. The tunnel, which is at an average depth of 80 feet, is constructed mostly in Esopus shale and for a short distance in a seamy limestone having an eroded surface and dipping at points below tunnel grade. The tunnel has a rectangular section 5′×7′, just large enough to allow a few men to work and lay the 24-inch pipe. It was found very difficult to construct short stretches of this tunnel in the usual manner, as large runs of soft material (water-bearing sand) from the surface of the rock was caused by the excavation, the street surface overhead settling. It was necessary to use compressed air to penetrate the worst stretch. After the locks were installed, the soft ground was easily passed.

Compressed Air for Soft Ground. This tunnel, although small, illustrates very well the advantage of compressed air for passing soft ground. Many instances have occurred where great expenditures have been made to penetrate heavy water-bearing material, using ordinary timbering methods at the cost of great delay and danger to surrounding property, due to loss of ground and runs into the excavation. As in this case, with the installation of air locks and the use of moderate air pressures, no difficulty would have been experienced, the cost being not much more than ordinary work without compressed air. Outside of large cities, where the compressed-air men are strongly organized, men can be secured for work in moderate pressures, say, up to 20 pounds, at slightly increased wages. A proper installation of air locks will permit the prosecution of the work at almost the same rate as outside work. The additional expenditure for compressed air is not a large item. A central air plant, as originally installed for Contract 48, consisted of one Ingersoll-Rand two-stage air compressor with a capacity of 1200 cubic feet of free air a minute compressed to 80 to 100 pounds. This air was distributed to over 12,000 feet of pipe from 6 to 2 inches in diameter. The shafts were equipped with derricks and small head frames operated by hoisting engines.

The total of Contract 48 was $146 631 some of the principal items being:

Shaft in earth,	linear ft.	$60
Shaft in rock,	"	70
Tunnel in rock,	"	15
Tunnel in earth	"	40
Lining tunnel in earth and rock,	"	2.25 (solid rock)
		14.00 (insecure rock)

Compressed-air Equipment. The compressed-air equipment installed consisted of an Ingersoll-Rand No. 2 upright compressor, capacity 500 cubic feet of free air per minute under 20 pounds pressure, driven by a 50-H.P. G.E. motor. Attempt to maintain a pressure of 15 pounds in 450 feet of heading failed, due to leakage through seams in the rock. By filling between 1-inch boards (supported on cap or posts) and the roof with earth, a pressure of 9 pounds was reached and used on the ordinary working pressure. The original high-pressure compressor mentioned furnished about one-half the air used in the heading. The ground, which originally could not be kept from running into the heading, now worked like putty. Air was observed to bubble up in a brook 1200 to 1500 feet from the tunnel.

Contract 59.

Highways around Ashokan Reservoir. This contract provided for the construction of 27½ miles of road around the reservoir and was awarded to C. P. Bower Construction Co., December, 1909, for $323,861. The main items are:

Earth excavation, cu.yd.	$0.55
Rock excavation, "	1.05
Concrete masonry, "	7.98

A part of the excavation was done by hand. A No. 1 Thew automatic shovel was successfully used for the bulk of the excavation, although the cuts were usually light.

Operation of Ashokan Reservoir and Headworks.

The following is given to show how the Ashokan Reservoir is to be drawn upon and the various gate chambers, aeration basin, screen chambers, etc., are to be operated.

Depth of Water that can be Drawn from Ashokan Reservoir. Examination of the maps of locality of Ashokan Reservoir (Plates 25 and 34) will show that the land surface of Ashokan Reservoir (except for a small area in gorge of the Esopus between the dam and Bishop's Falls at Olive Bridge about one-half mile above) is all above elevation 490, the level of the invert of the cut-and-cover aqueduct below the gate houses. Were the reservoir drawn to this elevation there would remain only a long narrow pool in the Esopus gorge above the dam and various isolated pools in the basin. The gates are so arranged that the full capacity of the aqueduct can be used with water surface as low as elevation 516, making 74 feet available for the West Basin and 71 feet for the East Basin.

East and West Basins. As the Beaverkill has a drainage area of only 17 square miles (against 240 for the Esopus) it can only furnish a very small amount of water to the East Basin, which will receive its supply from water going over the overflow weir which separates it from the Esopus or West Basin, or its level may be maintained by the opening up of the gates of the Dividing Weir gate house. (See Plate 55.) The floods of the Esopus will after raising the West Basin to above elevation 590 pass over the Dividing Weir over 1000 feet long and to a depth of 20 feet before overtopping dams or dikes, a vastly greater flood than any ever recorded.

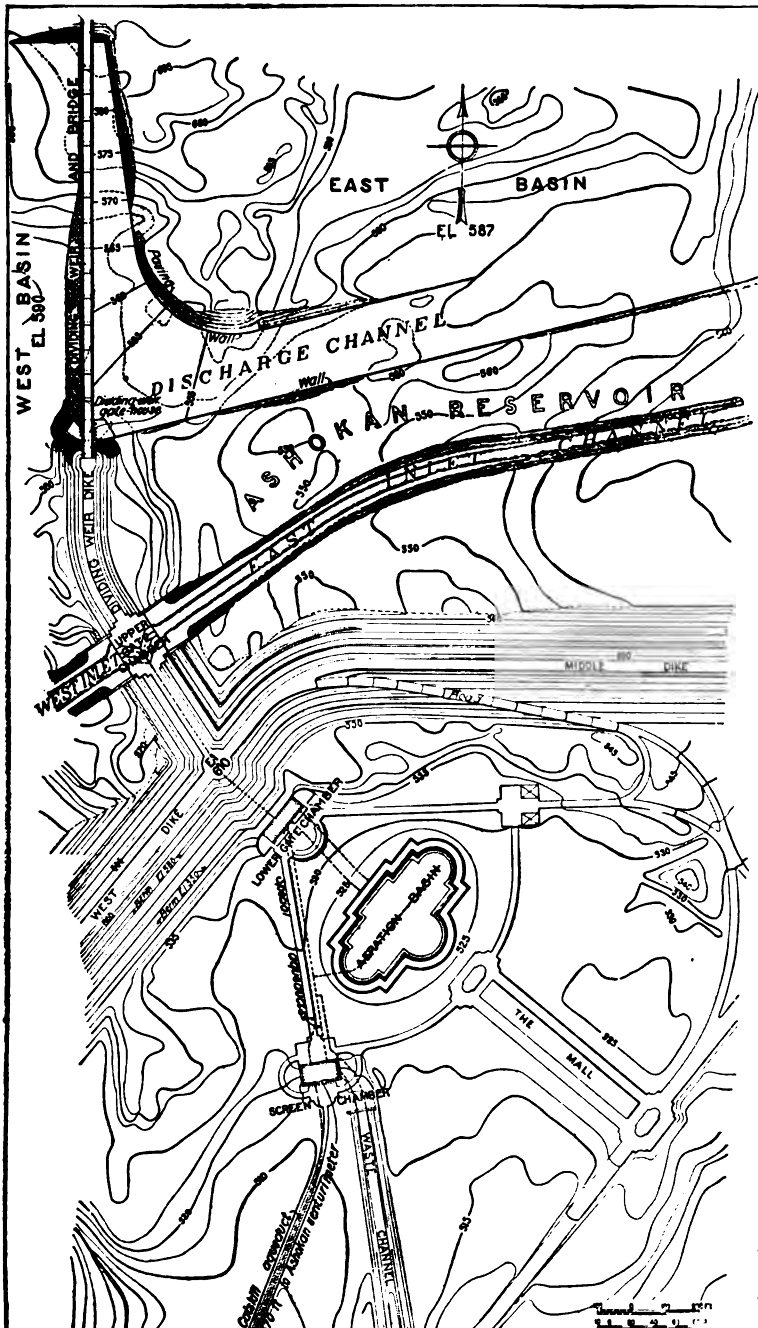


PLATE 55.—Plan of Structures at Outlet of Ashokan Reservoir and Beginning of Catskill Aqueduct, Showing Location of Dividing Weir, Upper Gate Chamber, East and West Inlets, Lower Gate Chamber, Aeration Basin, Screen Chamber, etc.

Below the dividing weir a wide discharge channel, later to be under water, is to be excavated to carry away the flood which after raising the East Basin to elevation 587 will overtop the Waste Weir two miles below. This weir has a crest about 1000 feet long, discharging into a steep concrete-lined channel leading to a runway of great capacity, tributory to Esopus Creek about 3 miles below the main dam.

Upper Gate House. The upper gate house, being located on ground only 15 feet below the water surface of the reservoir, requires an excavation about 80 feet deep with inlet channels to the Esopus and Beaverkill, to enable the reservoir to be drawn down to the level of outlet aqueduct. The West inlet channel, 5800 feet long, begins at the Esopus at elevation 490, has a cross-section in earth of 40 feet at bottom, 1 on 2½ side slopes. The East Inlet channel begins at the Beaverkill at elevation 500. It is excavated in rock, and has a minimum bottom width of 26 feet with sides 6 on 1 or flatter.

Pressure Aqueducts. Under the upper chamber are two aqueducts, the lower with invert, at elevation 492 feet, of horseshoe shape, 11′ 6″×11′ 5″; the other oval, 9′ 6″×14′, at elevation 506.5 feet. These two aqueducts, about 600 feet long, lead to the lower gate chamber at toe of slope of West Dike. Being required to sustain a maximum head of about 100 feet, they are known as pressure aqueducts, and were built in a trench on center line of dividing weir dike. The function of the upper gate chamber is to deliver water from different depths as desired to the pressure aqueduct, but not to control, except to a limited extent, the volume of flow out of the reservoir. The lower gate chamber receives the flow from the pressure aqueducts and allows it in any desired volume to pass into the Catskill Aqueduct, either directly or through an aeration basin to be described later.

Screen Chamber. At the head of the cut-and-cover aqueduct is a chamber containing fine screens, the function of which is to prevent the passage of material too fine to be caught by the coarse mesh of the upper gate chambers.

After passing through the screen chamber the water is measured in a Venturi meter built in a depressed portion of the cut-and-cover aqueduct.

Upper Gate Chamber. The upper gate chamber opens toward the water and the inlet channels of the East and West Basins, the chamber being supplied with coarse bronze screens. Cast-iron grooves are concreted in the sides of the chamber, and stop planks placed in these so as to enable the water to be drawn from any desired depth. Next the water passes through short steel pipes fitted at the inlet end with a sluice gate, at the center with a gate valve, and at the outlet end with a stop disk for emergency use. The center of the sluice gates is about opposite the center of the pressure aqueducts, and only 50 feet distant.

Lower Gate Chamber. From the pressure aqueduct at the lower gate chamber a battery of 60-inch steel pipes lead upward from the floor of the chamber. These pipes are controlled by a battery of 60-inch gate valves placed next to a manifold out of which a battery of pipes lead to reinforced concrete conduits discharging into an aerator basin, these pipes in turn being controlled by 60- and 48-inch valves, some of them of special construction.

Special Aqueducts to Screen Chamber. To provide for the use of the aqueduct when aerator is out of commission another battery of pipes lead directly from the pressure aqueducts to two similar special aqueducts discharging directly into the screen chamber, about 700 feet distant. The discharge into these aqueducts is controlled at the lower gate chambers by a gate and control valve. The aqueducts leading directly to the lower gate chamber reach hydraulic grade just above the screen chamber. In order to prevent the aqueduct below the screen chamber from being under a head which could readily be obtained from the pressure aqueducts by opening too wide the valves at the lower gate chamber, they are arranged to overflow into a waste channel of large capacity, which passes under the screen chamber and into an open channel to the Beaverkill.

Turbines at Lower Gate Chamber. To make use of a portion of the head available at the lower gate chamber when the reservoir surface is considerably above hydraulic grade at the screen chambers, a 48-inch steel pipe leads upward to the floor of the gate chamber, discharging into two turbines, whose draft tubes discharge into the lower special aqueduct to screen chamber. These turbines will supply light and power for local service at the gate chambers and in vicinity.

Below is appended a detailed description of the operation of the headworks, taken mainly from the Catskill Water System News of Aug. 5, 1911.

Headworks. "The structures comprising the headworks of the Catskill Aqueduct at Ashokan Reservoir are necessarily of rather complicated design. To make their functions more readily understood, the accompanying sketch, Plate 59, has been prepared with the tops of the structures removed at critical places in such a manner

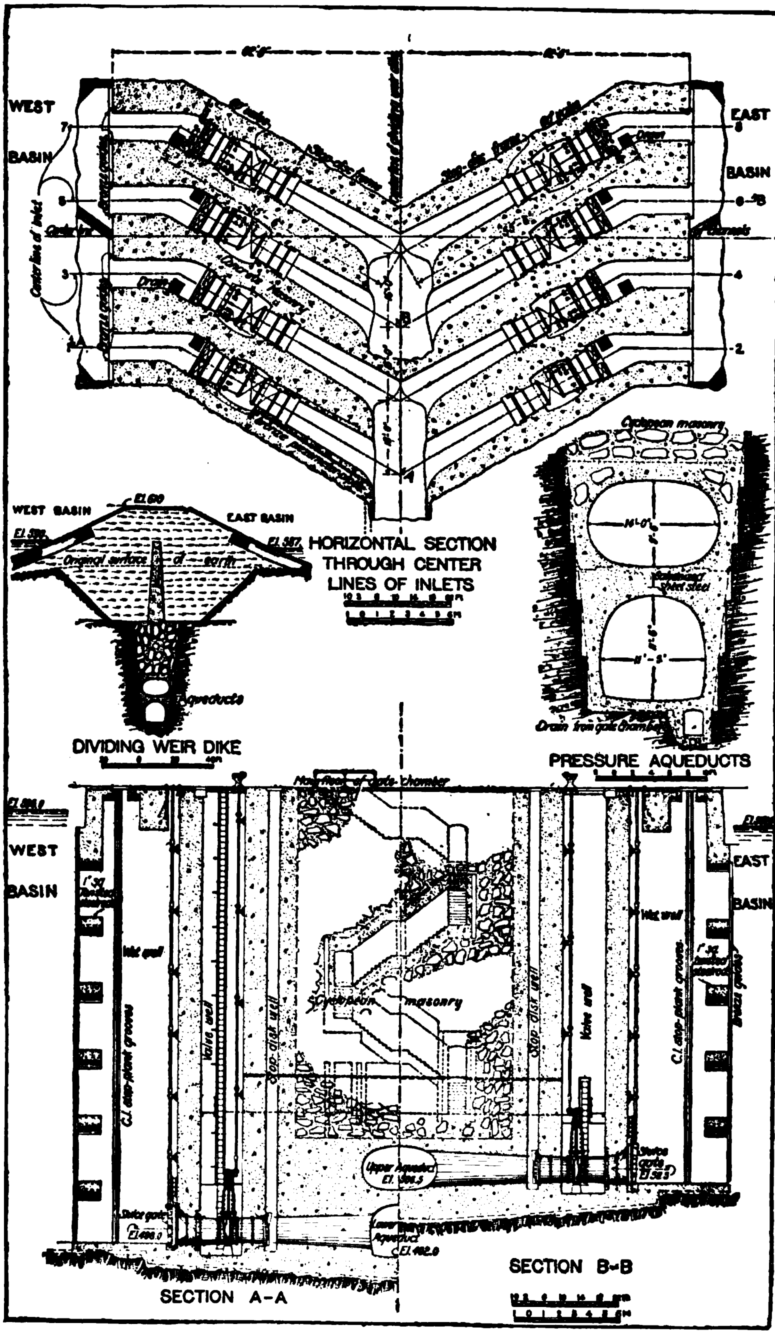


Plate 56.—Upper Gate Chamber at Ashokan Reservoir. Sections and Details of Pressure Aqueducts and Dividing Weir Dike.

PLATE 57.—View of Upper Gate Chamber, Upper and Lower Special Aqueducts, for Draining Water from Reservoir under Dividing Weir Dike at Right, 60-inch Gate Valve being Placed. Contract 3.

as will quickly convey the relation of elevations, sizes and other features of the water passages without detailed dimensions.

"The headworks include the upper gate chamber and pressure aqueducts in Contract 3 and the lower gate chamber, screen chamber, aerator, special aqueducts, waste weirs and channel in Contract 10.

Upper Gate Chamber. "The upper gate chamber, not shown in sketch, is located in the dividing weir dike and provides for drawing water from either or both basins of the reservoir at any elevation, controlled by shutters lowered in the stop plank grooves of the outer wells. On the outer faces of the chamber bronze guides are provided in which coarse racks will be installed from preventing logs or other large objects from getting into the aqueduct. In designing the water passages the Venturi principle was utilized as far as possible to reduce the loss of head at the contracted section of the valves. Under normal conditions there will be no control of quantity in this chamber, the 60-inch valves being either wide open or closed. However, when the reservoir is being first filled, and perhaps at other times, it may be convenient to temporarily control the flow by the 3'×8' guard gates upstream from the valves.

"From the upper gate chamber the water is delivered to the lower gate chamber through one or both of the pressure aqueducts, built of plain concrete in a deep rock trench which is backfilled with concrete sufficient of its own weight to withstand the upward water pressure.

Lower Gate Chamber. "The lower gate chamber, where the manipulation of the flow will take place, is located at the junction of the West and Middle dikes. From here the water may be delivered directly into the screen chamber through the two special aqueducts or by way of the aerator. The 48-inch control valves of special design permit manipulation for the discharge of any desired quantity without the annoying "chattering" so often attendant on control by large gate valves and sluice gates. A 48-inch connection from each aqueduct provides for power development for operating gates, lighting, etc. Bronze gauge pipes from the standard aqueduct below the screen chamber lead to float wells in the lower gate chamber so that the person in charge of the operation of the valves can tell directly the depth of water in the aqueduct below as uninfluenced by conditions of cleanliness of the screens. It can be seen from the sketch that the lower pressure aqueduct supplies water through four valves to the lower special aqueduct and also to the aerator pipes through two valves shown in the lower right-hand corner of the sketch. The

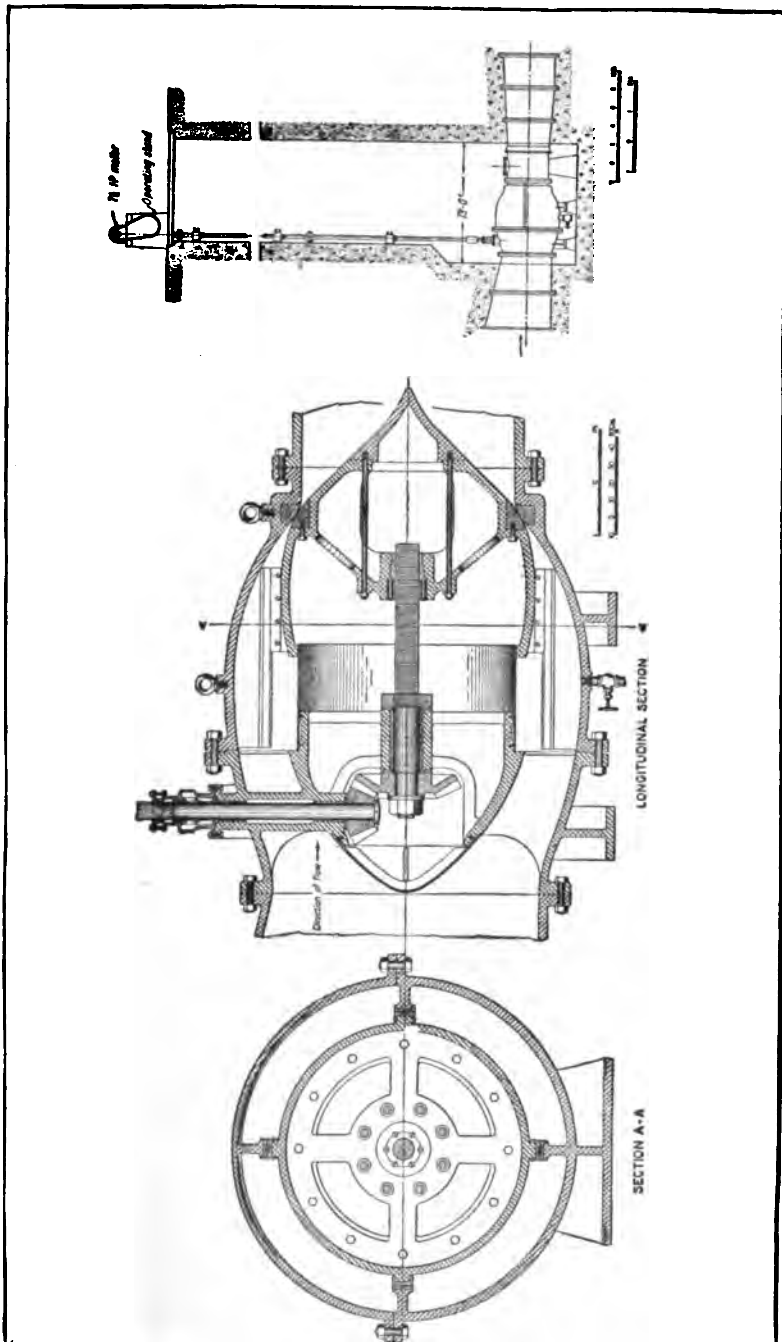


PLATE 58.—Headworks of Catskill Aqueduct. Lower Gate Chamber, 48-inch Control Valve.

upper pressure aqueduct supplies the upper special aqueduct through two valves shown in the upper right-hand corner of the sketch and also the aerator by means of two valves directly adjacent to similar valves obtaining water from the lower pressure aqueduct. The arrows in all cases indicate the direction of the flow. The water from the aerator basin flows over a weir into the upper special aqueduct.

Special Aqueducts. "The somewhat unusual section of the special aqueducts between the lower gate chamber and the screen chamber is due to several conditions. The lower one, for which a $6' \times 15'$ waste gate is provided in the screen chamber, is to be used for emptying either basin of the reservoir in the early stages of operation in case it may be advisable as a means for overcoming possible undesirable conditions of the water when the reservoir bottom is first flooded, or for other reasons. This necessitated running the aerator outlet over the top of the lower aqueduct so that the aerated water can be delivered through the upper aqueduct at the same time the lower one is used for wasting. The water area is approximately a mean between that of the pressure aqueducts and the standard cut-and-cover section below the screen chamber. The inside radius of the arch, 6½ feet, is used also for practically all the other small arches in the vicinity, in order to simplify form work.

Overflow Weir. "Just above the screen chamber an 100-foot overflow weir is provided in the lower special aqueduct with the crest at about the hydraulic grade line and a 40-foot one in the upper aqueduct primarily to prevent undue head on the aqueduct, below the screen chamber. These weirs are designed to discharge the maximum quantities of water that can reach them in excess of one aqueduct capacity, assuming all gates above open. The weir for the lower aqueduct will also carry whatever the waste gate will not discharge when water is being wasted. A waste channel covered for 100 feet from the screen chamber will discharge into the Beaverkill gorge.

Screen Chamber. "Piers with stop plank grooves divide the screen chamber into two symmetrical parts so that either side can be used in screening the water. Economy has been sought by an arrangement of grooves permitting screens to be placed in a broken line like a Greek border, thus providing the necessary screen area in a structure of minimum size for the purpose. The arrangement will also permit screens to be fastened together as a sort of hamper with the upstream face open, so as to handle three lines of screens on one operation. Grooves have been provided immediately below the

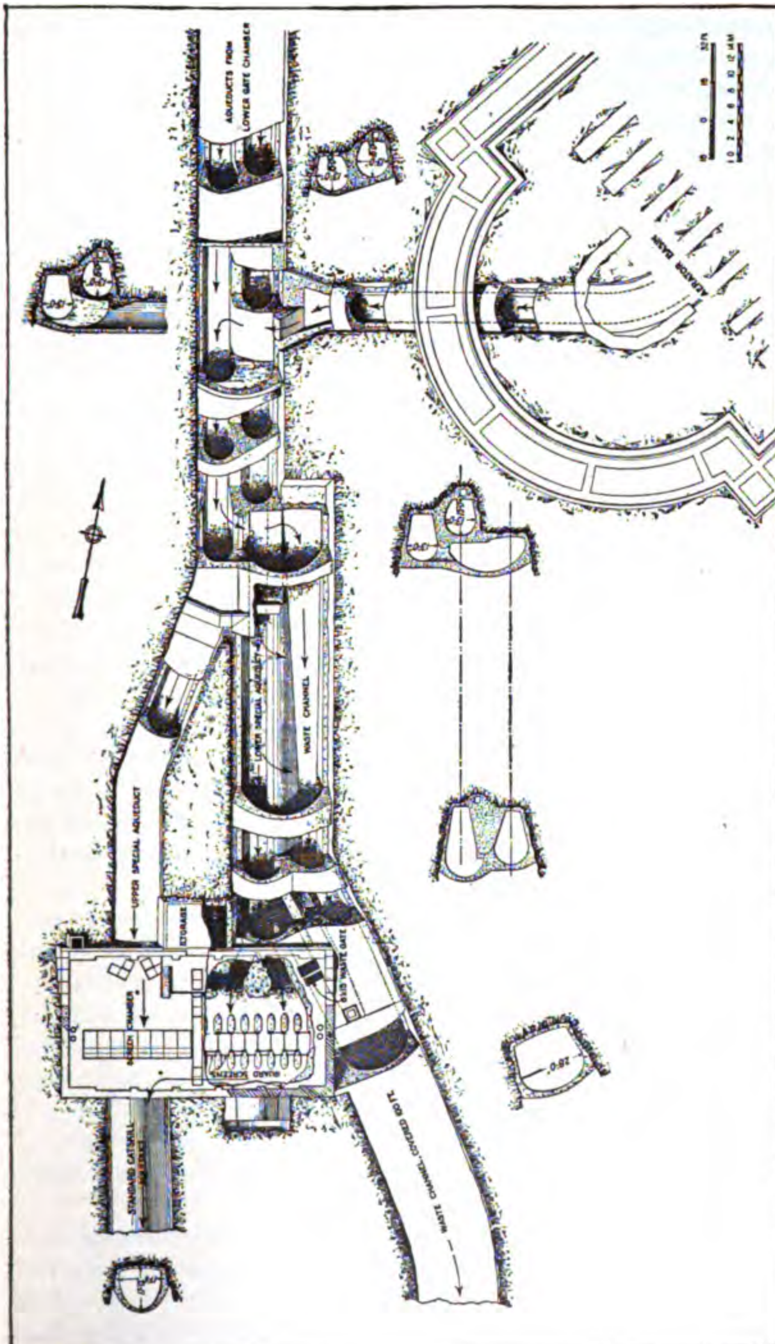


PLATE 59.—Sectional Plan of Headworks of Catskill Aqueduct between Aerator and Screen Chamber.

main screening area for guard screens to be placed during the operation of cleaning the regular screens. Water under pressure from the reservoir will be available for washing screens on the washing floor at one side of the chamber. Float wells in this chamber will record losses of head in passing the screens. Stop planks and screens not in use can be stored in a room for this purpose into which a track runs from the main floor. Whenever it is desired to waste water through the waste channel, stop planks will be inserted in grooves located in piers immediately above the main screens.

Capacity of Headworks. "The headworks are so designed that it will be possible to draw the full capacity of the Catskill Aqueduct through the lower aqueduct, from either basin of the Ashokan Reservoir, with the water as low as elevation 518 or 519. If the lower aqueduct is supplied from both basins of the reservoir the full capacity can be drawn when the water surface in the reservoir is as low as about elevation 516. The upper aqueduct, on account of throttling at the two 48-inch control valves in the lower gate chamber, can deliver the full Catskill Aqueduct capacity only down to about elevation 540 in the reservoir. With all valves on both aqueducts wide open from both basins the full capacity can be drawn as low as elevation 514. These elevations are for flow directly to the screen chamber without aeration. With the reservoir full (elevation 587 and 590) the maximum discharging capacity for drawing off either basin of the reservoir through the lower aqueduct is 2500 to 3000 cubic feet per second. Starting with the East Basin full it would take about fifty days to empty it in this way down to elevation 520 and eight days more to drain out the remainder, with no allowance for inflow during the period of emptying."

Aeration Basin. Reinforced aqueducts from the lower gate chamber discharge into an aeration basin. This basin is about 200′×400′, of irregular shape, and is to be the feature of an elaborate landscape treatment at this point. In it will be several hundred bronze nozzles discharging the entire flow of the aqueduct in a series of jets so as to free the water from objectionable gases and odors and to charge it with oxygen. Passing through the chamber is a horseshoe aqueduct with a side slit at the top to receive aerated water. This aqueduct discharges over a weir into the special aqueduct just above the screen chamber.

Soil Stripping. Early in the work an extensive investigation was conducted as to the advisability of stripping the soil from the bottom and sides of the Ashokan Reservoir, and a thorough report was made in 1907 by Messrs. Allen Hazen and Geo. W. Fuller (see

Annual Report, 1907). They concluded that the cost of stripping the Ashokan Reservoir, estimated as over $5,000,000, was not warranted by any commensurate improvement in the water, as follows:

Report of Hazen and Fuller. "1. The stripping of the sides and bottom of a reservoir will ordinarily prevent stagnation of the bottom layers for a period of years, the length of which depends upon various local conditions. In the Boston reservoirs this period does not seem to exceed from ten to twenty years.

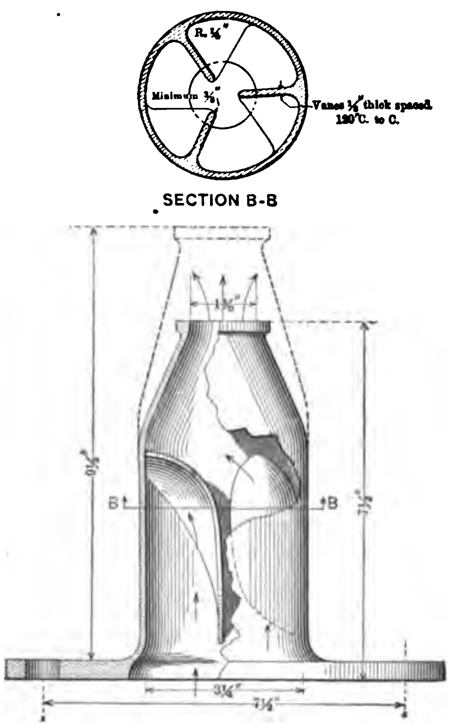


PLATE 60.—Cross-section of Special Bronze Nozzles Used for Aerating Water Drawn from Ashokan and Kensico Reservoirs.

"2. Ultimately it makes comparatively little difference as to stagnation of the bottom layers whether the sides and bottom of a reservoir are stripped or not.

"3. By aeration and filtration of the bottom water of deep reservoirs there can be obtained a better quality of water without the benefit of stripping than it is possible to obtain with the aid of stripping in the absence of aeration and filtration.

"4. In the absence of stripping substantially as good a quality of bottom water may be obtained, after aeration and filtration, as in the presence of stripping. In fact, as just stated, decolorization and purification are facilitated by the absence of stripping due to bacterial agencies which make some of the iron in the soil available as a coagulant.

"5. In view of the above and as aeration and filtration will ultimately be required in order to obtain satisfactory results in this climate, present evidence and experience indicate that beyond grubbing a reservoir it is unwise to spend money for further removing organic matter from the bottom and the sides."

Operation of Aerator. A detailed description of the similar Kensico aerator and its workings is here appended, taken from the Catskill Water System News of June 20, 1911:

"The aerator basin is a shallow pool 460 feet long and 240 feet wide at its widest part. It is lined with concrete and is surrounded by a concrete apron 20 to 25 feet wide to insure the return to the basin of any water blown beyond its enclosing walls. Its shape is that of a rectangle to which semicircles have been added on the ends and on one long side. The object of the pool is to collect the water and deliver it into the aqueduct through an outlet conduit extending under the basin on its long axis, and having a long narrow opening in the top to receive the water.

"Water is delivered to the basin through a group of concrete conduits from the lower effluent chamber. In the basin these conduits branch into smaller pipes which run parallel to the long axis of the aerator and in the top of which are set nozzles for discharging the water vertically into the air. There are seven of these nozzle pipes, each one of which feeds about 215 nozzles. In addition there are groups of nozzles in each of the three semicircular portions of the basin, making the total number of nozzles about 1600.

"Experiments have been performed in the endeavor to select a type of nozzle most suitable for aeration. The design which will probably be adopted consists of a cylindrical base with a short conical tip. Within the base on the sides of the nozzle are fixed three vanes which extend into the waterway. They start at the bottom parallel to the direction of flow and gradually assume an inclination of about 60 degrees with the element of the cylindrical base. The result is that the water issuing from the nozzle is thrown outward from the tip and forms a very regular fan-shaped jet in which a distinct whirling motion is perceptible. It was noted that this type of nozzle is more efficient in breaking up the water, while at the same time the jet is more stable in the wind than that from other types.

"The available head for aeration is about 20 feet at the base of the nozzle, which gives a jet about 15 feet high. The jets for the most part are spaced uniformly about 16 inches apart so that there is an interference of two adjacent jets almost as soon as the water issues from the orifice, and a nozzle line when in operation will appear as a solid wall of spray. It is intended, however, to form breaks in the lines by omitting the nozzles at two places in each line so chosen that two lanes or vistas about 15 feet wide will be formed across the aerator. The borders of these vistas as well as the ends of the nozzle lines will be emphasized by placing there additional nozzles, forming symmetrical clusters.

"In the small semicircular units the arrangement and design of nozzles is such as to give some variety to the appearance, with a view to helping the artistic effect. In the center, clusters of smooth nozzles without vanes are provided. These are surrounded by a line of the regular nozzles and outside of all is a line of special nozzles designed to give a wide low jet.

"It is intended to operate the aerator always under the full available head and to meet variations in flow by shutting off certain portions rather than by throttling. To this end, the nozzles are divided into groups of varying capacity, each group controlled by a separate gate in the lower effluent chamber. By this means, the flow may be increased or diminished by stages of about 25 M.G.D. The groups are so arranged that with any combination of units in service there will be a symmetrical arrangement of jets in the basin."

Venturi Meter. The first apparatus for measuring the flow of water in the aqueduct is the Ashokan Venturi meter. This structure is a few hundred feet below the screen chamber at a depression formed by a small stream. The total length is about 400 feet, depressed so that the throat is under a head of about 25 feet. It is all of reinforced concrete, changing at each end from the shape of the standard horseshoe cut and cover to the circular throat casting 7 feet 9 inches in diameter. To obtain accurate sections of aqueduct at the points where Piezometer tubes are attached, two bronze castings are set, known as the upper Piezometer casting and the throat casting. The upper casting is 17 feet 6 inches in diameter and 1 foot wide, the lower about 7 feet 9 inches in diameter and about 8 feet long, the upper casting being set about 30 feet upstream from the throat. Two tapered sections occupy a length of about 148

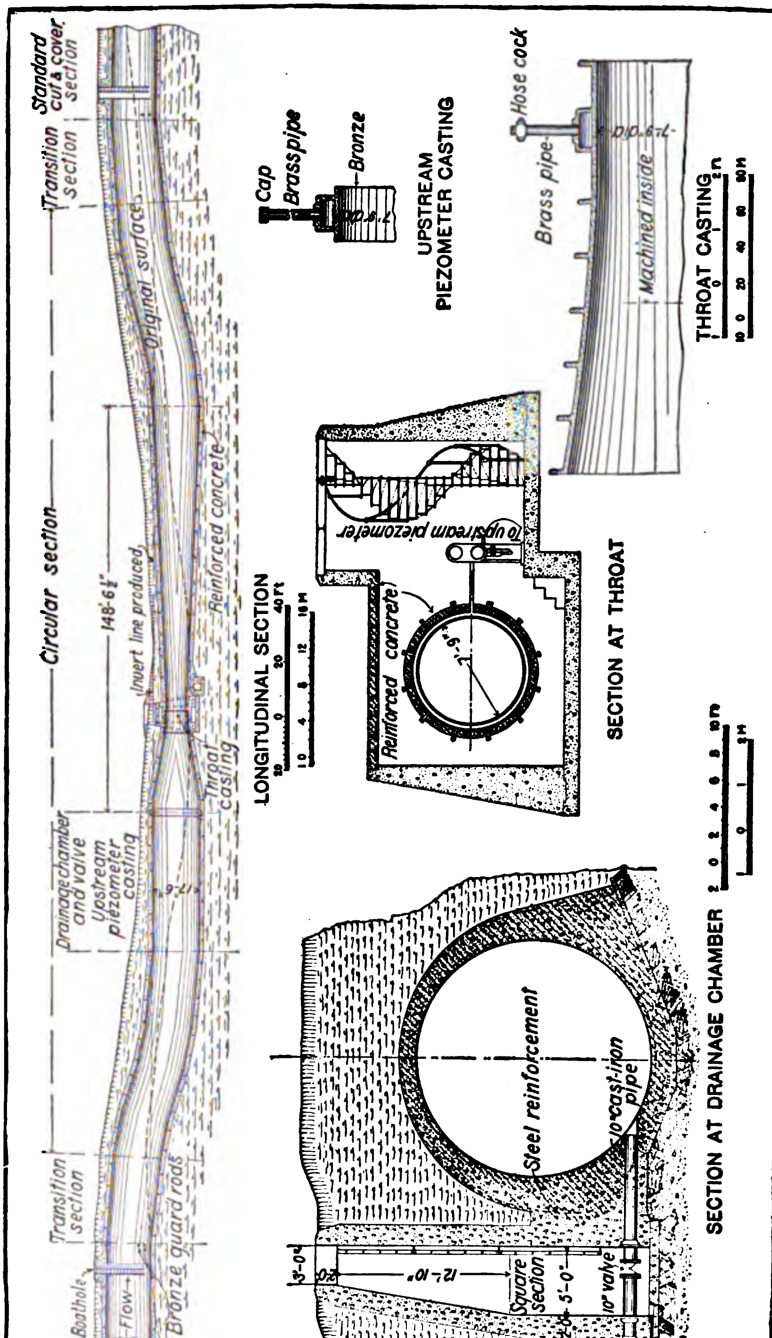


Plate 61.—Venturi Meter at Beginning of Catskill Aqueduct. Longitudinal and Cross-sections.

feet. Adjacent to the throat casting a small chamber is built to contain the automatic recording apparatus.

Three other Venturi meters are built along the line of the aqueduct, at Pleasantville to measure the flow into the Kensico Reservoir, at Valhalla to measure the outflow of the Kensico, and in the City Aqueduct tunnel to measure the flow into the City of New York. In addition, there are several gauging manholes by which the water in the cut-and-cover aqueducts can be measured by ordinary current meters. These manholes are conveniently built so that the meter can run on two bronze rails transverse to the aqueduct, and the flow obtained at numerous points in the rectangular section at the gauging manhole. With these facilities it will be easy to ascertain the exact flow in the aqueduct at numerous points, thus giving a valuable check on the leakage from various stretches, and evaporation and losses from the reservoirs. The aqueduct being of unprecedented size with numerous types of structures, valuable and interesting data should be obtained.

CHAPTER VII

ESOPUS CUT-AND-COVER AND PEAK TUNNEL

Contract 11.

Amount of Work under Contract 11. This contract comprises about 6½ miles of concrete aqueduct in cut-and-cover, and the Peak tunnel 3470 feet long. Its northerly end adjoins the Esopus steel pipe siphon (Contract 62) 1 mile south of Brown's Station and runs continuously except for a small gap at Tongore Siphon (Steel Pipe Contract 62) to a point 2½ miles northwest of High Falls Station at Shaft No. 1 of the Rondout Siphon (Contract 12). The work lies in the watersheds of Esopus and Rondout Creeks, the divide between being pierced by the Peak grade tunnel. From the northern to the southern end is a distance of 7¼ miles measured along center line. Next to Contract 2 and Contract 55 this is the largest cut-and-cover and grade-tunnel contract on the entire aqueduct. It was awarded to Stewart-Kerbaugh-Shanley Co., the lowest bidder, for $2,368,920; time allowed for completion, forty-eight months from notice to begin work, served Aug. 5, 1908.

Location of Aqueduct. The aqueduct on Contract 11 is located in a rather wild, inaccessible country and skirts the base of the Catskill foothills, cutting numerous bluestone ledges of the Hamilton formation and hills of glacial drift. It is remote from railroads and reached only by very rough country roads with numerous steep grades.

Because of the roughness of the country to be traversed, the location of this aqueduct presented all the problems likely to be met with on work of this class. Its location was very carefully made and was reviewed by consulting engineer Horace Ropes. At the north end, instead of following the minimum cost contour, long tangents with rather deep average cut were adopted and a saving made in distance and probably in cost.

The central section passes through many abandoned bluestone quarries and ledges, a very puzzling country in which to place the aqueduct. There it was necessary, in order to keep the aqueduct clear of embankments, to make numerous deep rock cuts. At the

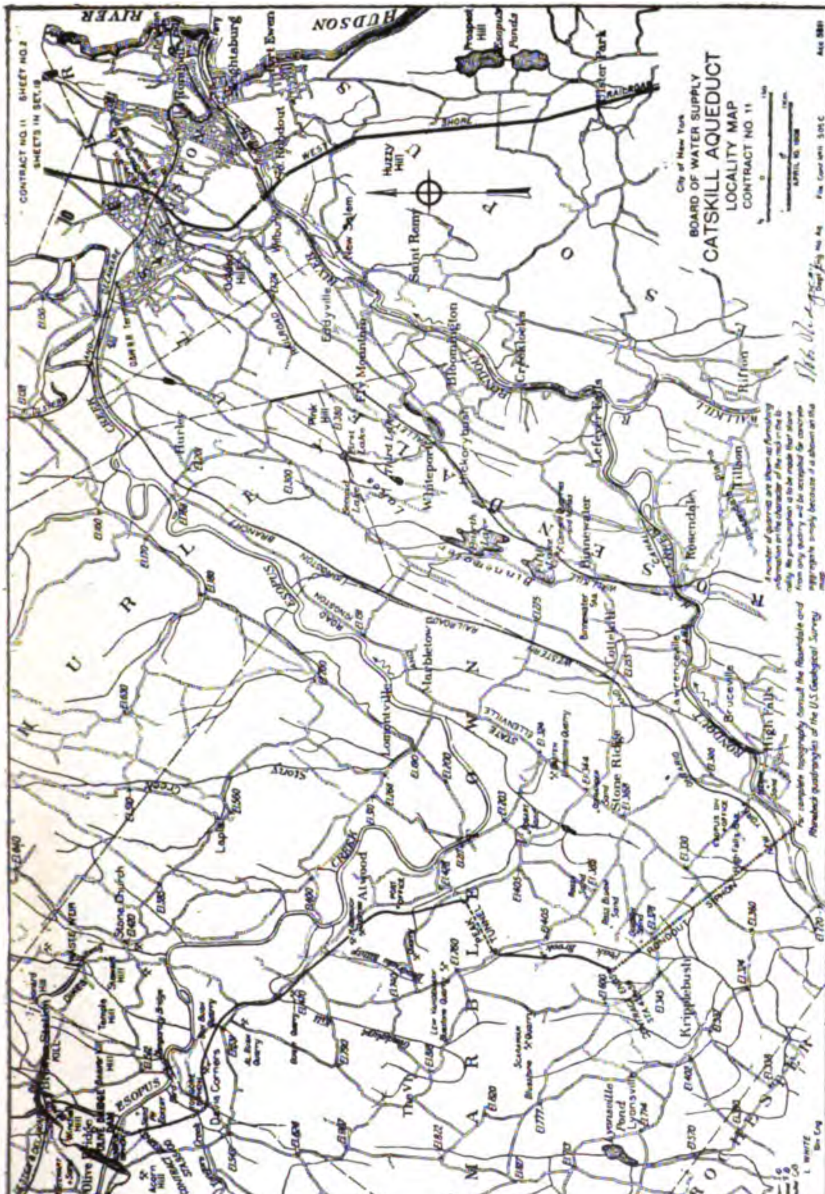


PLATE 62.—Contract 11. Locality Map Showing Position of Aqueduct Relative to Surrounding Country and Neighboring Contracts.

little town of Atwood, the aqueduct traverses a precipitous side hill overlooking the Esopus. To provide a safe location it was necessary to make a rock cut about 900 feet long averaging over 25 feet in depth, in order to place the structure well back from the face of the cliff in sound rock.

A cut-and-cover location around the Peak mountain was nearly adopted, but careful study showed that the Peak tunnel location would save much in distance and probably in cost. The cut-and-cover location would have had the advantage, however, of giving a continuous right of way for a railway and pipe lines along the aqueduct. Until the Peak tunnel was driven through and a through track laid, the work was cut into two parts, that south of the Peak being much more accessible.

Avoidance of Embankment Section. Numerous alternate locations of the center line of the aqueduct were made on the plane table contour map, staked out in the field, profiles run over them and cost comparison made before the final location was decided upon. A remarkable feature of this contract is that in nearly 7 miles of rough country only about 300 feet were built on embankment, the various crossings of streams, gullies, etc., being made high enough to keep the aqueduct in cut, except of course for the very short stretches necessary for culverts, in which case the invert of the aqueduct rests directly on the heavy culvert arches.

Contract Prices. As Contract 11 is representative of many, tabulation of the bid prices of the successful bidder is here given:

On the basis of contract quantities and prices the cost of cut-and-cover aqueduct to the city has been estimated at $60.66 per foot, cost of grade tunnel at $86.55. On actual quantities the cost was $59.25 per foot of cut-and-cover aqueduct, of grade tunnel $68.65. Cost of culverts averaged about $2.70 per foot of main aqueduct, costing from $2180 for 6-foot culvert to $1224 for 3-foot culvert. The Peak tunnel proved to be in such a good sound rock, requiring practically no timbering, that the quantities of excavation, etc., were much lower than originally estimated.

Required Progress. The following is the schedule of required progress contained in the contract:

Time elapsed after service of notice to begin work.	Percentage to be done of total amount of contract, based on the Approximate Statement of Quantities and the contract prices.
6 months	1 per cent
12 months	10 "
24 months	50 "
36 months	85 "
48 months	100 "

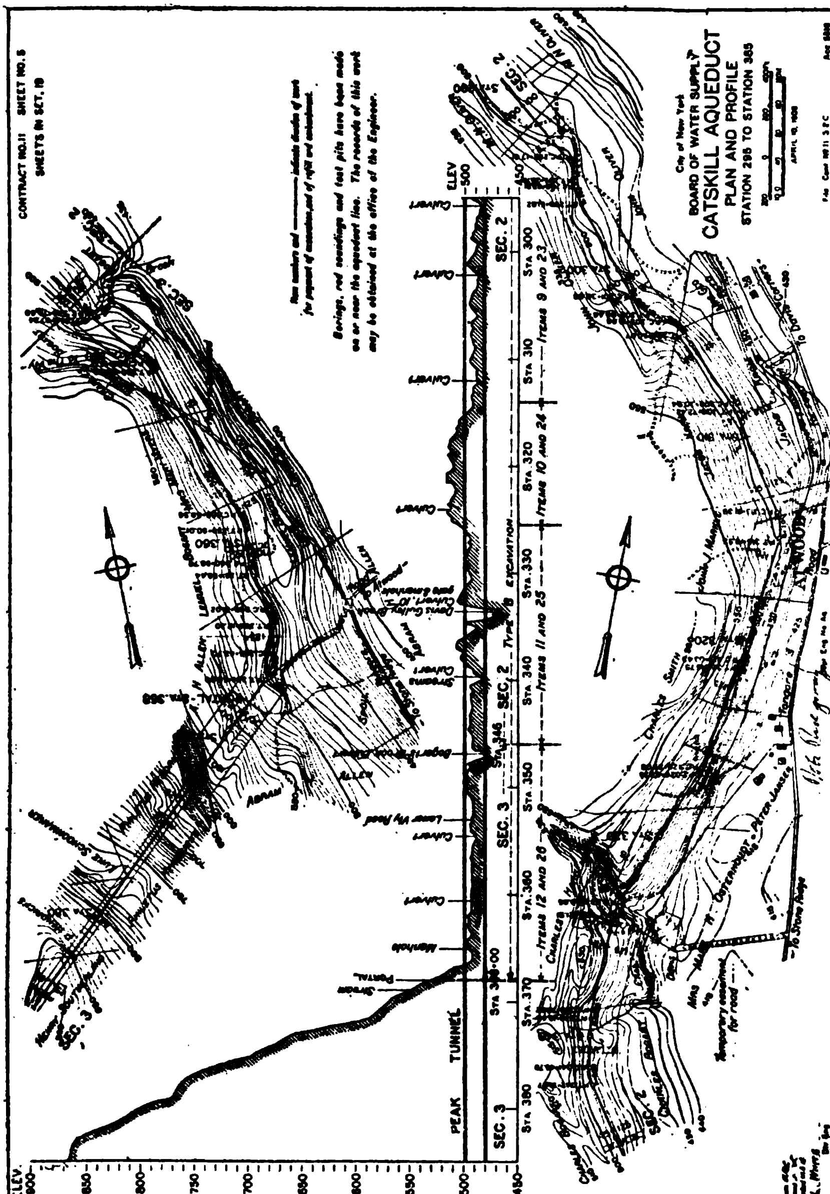


Plate 63.—Contract 11. Contract Plan and Profile of Portion of Aqueduct above Peak Tunnel, Showing Contours at Atwood Deep Rock Cut.

BOARD OF WATER SUPPLY OF THE CITY OF NEW YORK

CONTRACT 11, A PORTION OF THE ESOPUS DIVISION OF THE CATSKILL AQUEDUCT

Canvass of Bids opened July 23, 1908

STEWART-KERBAUGH-SHANLEY COMPANY, 527 Fifth Ave., New York City.

Item.	Description.	Unit.	Quantity.	Price.	Amount.
1	Removal of top soil	Cubic yard	65,000	.57	37,050.00
2	Open-cut excavation, Stations 95 to 110, Type B	"	20,000	.48	9,600.00
3	" " " 110 to 122+25, Type A	"	32,000	.44	14,080.00
4	" " " 130 to 160, Type A	"	61,000	.48	29,280.00
5	" " " 160 to 210, Type A	"	89,000	.55	48,950.00
6	" " " 210 to 237, Type B	"	27,000	.74	19,980.00
7	" " " 237 to 256, Type B	"	35,000	.93	32,550.00
8	" " " 256 to 273, Type B	"	30,000	.48	14,400.00
9	" " " 273 to 314, Type B	"	41,000	1.09	44,690.00
10	" " " 314 to 325+50, Type B	"	38,000	1.50	57,000.00
11	" " " 325+50 to 346, Type B	"	31,000	.48	14,880.00
12	" " " 346 to 368, Type B	"	38,000	.80	30,400.00
13	" " " 402+70 to 407, Type A	"	15,000	.93	13,950.00
14	" " " 407 to 420, Type A	"	15,000	.51	7,650.00
15	" " " 420 to 478+50, Type B	"	75,000	.52	39,000.00
16	Refilling and embanking, Stations 95 to 110	"	21,000	.37	7,770.00
17	" " " " 110 to 122+25	"	22,000	.37	8,140.00
18	" " " " 130 to 160	"	45,000	.37	16,650.00
19	" " " " 160 to 210	"	76,000	.37	28,120.00
20	" " " " 210 to 237	"	55,000	.53	29,150.00
21	" " " " 237 to 256	"	19,000	.37	7,030.00
22	" " " " 256 to 273	"	21,000	.37	7,770.00
23	" " " " 273 to 314	"	75,000	.42	31,500.00
24	" " " " 314 to 325+50	"	8,000	.42	3,360.00
25	" " " " 325+50 to 346	"	32,000	.37	11,840.00
26	" " " " 346 to 368	"	33,000	.37	12,210.00
27	" " " " 402+70 to 407	"	3,000	.42	1,260.00
28	" " " " 407 to 420	"	24,000	.42	10,080.00
29	" " " " 420 to 478+50	"	77,000	.37	28,490.00

30	Surface dressing and grassing	"	42,000	.45	18,900.00
31	Concrete masonry for aqueduct in open cut and on embankment	"	165,000	5.42	894,300.00
32	" " " culverts, retaining-walls, etc	"	10,000	5.42	54,200.00
33	Dry rubble masonry and paving	"	5,000	3.00	15,000.00
34	Crushed stone and gravel	"	1,000	2.00	2,000.00
35	Sluice gates	Gate	4	75.00	300.00
36	Cast-iron pipes and special castings	Ton	8	100.00	800.00
37	Vitrified pipe	Linear foot	1,000	1.50	1,500.00
38	Timber and lumber	M. ft. B.M.	250	40.00	10,000.00
39	Testing portions of aqueduct	Portion	12	1000.00	12,000.00
40	" " " " , exceeding 200 feet in length	Linear ft. excess	2,600	5.00	13,000.00
41	Excavation in tunnel	Cubic yard	40,000	4.10	164,000.00
42	Additional trimming in tunnel	Square yard	400	5.00	2,000.00
43	Permanent timbering in tunnel	M. ft. B.M.	100	50.00	5,000.00
44	Temporary timbering in tunnel	"	50	50.00	2,500.00
45	Tunnel drainage	Linear ft. tun.	3,470	1.50	5,205.00
46	Forms for masonry lining in tunnel	"	3,470	4.00	13,880.00
47	Concrete masonry in tunnel	Cubic yard	11,000	4.92	54,120.00
48	Excess concrete masonry in tunnel	"	700	2.50	1,750.00
49	Brick masonry in tunnel	"	200	15.00	3,000.00
50	Dry packing	"	2,000	2.50	5,000.00
51	Drilling holes in rock or masonry	Linear foot	200	1.00	200.00
52	Steel pipes for grouting	"	1,000	.50	500.00
53	Portland cement	Barrel	250,000	1.50	375,000.00
54	Grout of Portland cement	Cubic yard	750	8.10	6,075.00
55	Stone boundary walls	Linear foot	63,000	1.00	63,000.00
56	Fences and guard rails	"	17,000	.25	4,250.00
57	Steel for reinforcing concrete	Pound	100,000	.05	5,000.00
58	Wrought iron, cast iron, and steel	"	6,000	.06	360.00
59	Bronze	"	2,500	.50	1,250.00
60	Cleaning up	Lump sum	....	....	18,000.00
	Totals	....	....	....	2,368,920.00

Time: 48 months. Bond required $400,000.00. Engineer's estimate $3,137,655.00.

The contract was completed on time.

Test Pits and Soundings. It will be noted from the itemized bid that no classification of excavation as earth and rock was made, but that the contractor bid on excavation, refilling and embanking in fourteen sections. Previous to the reception of bids the line of the aqueduct was carefully staked out, and test pits dug at close intervals, to the number of 200. These were left open, so that intending bidders could examine the material taken out of them and thus get an idea of what they were likely to encounter. Although not officially given out, from the test pits and numerous soundings the probable rock profile was plotted and given to the bidders by the engineers on the ground. This in connection with the information given by the test pits was ample to give a very good idea of the materials to be excavated.

Classification of Materials of Excavation. As a matter of general policy for the whole line of cut-and-cover, it was decided that no classification of material would be attempted, as it was felt that in the excavation of the surface rocks, much of which was decomposed and shaly, it would be hard to differentiate the rock from the overlying earth. This proved to be the case, as many of the cuts were taken out in one lift, the bottom rock being drilled through the earth, and after being blasted excavated with its burden by steam shovels or other tools.

Payment Lines. For the standard cut-and-cover section shown on Plates 11 and 12 definite payment lines were prescribed, so that the contractor knew in advance to what slopes he would be paid, these slopes being fixed for sections between definite stations. The engineers had no authority to modify slopes, but could move them outward if conditions warranted. The experience on miles of cut-and-cover work shows that the payment lines in dry, loose earth slopes, on type A, are liberal, but that it is difficult to excavate to the lines of the compact earth section and even more difficult to excavate to the lines of the rock section, for which 6 on 1 slope was prescribed, with 20 inches as a minimum thickness of side wall.

Difficulties of Excavation in Rock Cuts. In order to make reasonable progress in the laying of the aqueduct, it was necessary to excavate a considerable length of trench per day, which involved the handling of much material, so that hand methods were out of the question. This meant that power machinery had to be used, with frequent blasting in rock. This made it impracticable to excavate to the close lines of the rock section, unless the rock proved to be particularly good, which is seldom the case, as it was found that no matter what the variety of rock, the first few feet of the surface was intersected by numerous open seams and heads into which the powder tended to work, and as these seams seldom parallel the excavation at the proper distance, cuts tended to break wide. It is probable that by channeling the rock on each side, a close section of rock cut could be secured, but this would be enormously expensive, very slow and not contemplated by the contract.

Estimating Quantities from Payment Lines. In the preparation of the estimates the lines were usually moved outward in rock and compact earth sufficiently to cover the excavation made where contractors had exercised due care. Experience seems to show that in tunnels a close definition of payment lines is practical and just, but this does not appear to be the case in an open cut, due to weathering of the surface material. Some engineers are in favor of not prescribing in advance the slopes, but leaving this to be determined in the field by the engineers directly in charge. There is room for a fair difference of opinion, but it would appear that defining the payment lines leads to better bidding, the contractors having a well-defined idea as to what they will be required to do and for what they will probably be paid.

Specifications Contract 11. The specifications of Contract 11, like all those issued later, are indexed by means of the payment items. All references to any item are found under the number of that item and in consecutive order. Thus section 2.16, is the sixteenth section under item two, and so on. The items are easily found by means of heavily lettered numbers in the right-hand corner. Some of the principal sections of this contract are here given:

One Price of Excavation. Section 2.13. "One price only is to be paid under each item, to cover the excavation of all materials, except top-soil. Payments shall be made under each item for the materials excavated according to orders, between the designated stations, for the aqueduct and its appurtenances, for rights of way across the aqueduct lands, for public highways, whether temporary or permanent, and for such other purposes as may be directed. Nothing in this contract shall be so construed as to include payment under Items 2 to 15, any materials taken from borrow-pits, sand and gravel-pits or quarries, or from other excavations made for the purpose of obtaining materials. Materials re-excavated from storage piles shall not again be paid for as excavation. No direct payment shall be made under Items 2 to 15 for excavations of whatever nature made in connection with the Contractor's plant, his roads, or railroads, or for his other requirements in carrying out the provisions of this contract.

Payment Lines for Excavation. Section 2.15. " Excavation for aqueduct trenches shall be measured for payment as of the cross-section included within the prescribed limits hereinafter described, and of the actual length made in accordance with directions, as measured along the axis, or center line, of the aqueduct. If the top-soil has not been removed, the measurement shall be made to the actual surface of the ground as it exists when the Contractor enters upon any given portion of the trench location. Wherever the top soil shall have been removed in accordance with directions, the measurement shall be made as though the material were excavated from a surface 1 foot below the original surface of the ground.

Miscellaneous Excavation. Section 2.18. " All excavations for structures other than the aqueduct proper, including those for culverts, foundation piers under the aqueduct, and pipes, shall be measured for payment to the subgrade directed for such excavations, and to vertical lines 1 foot outside of the neat lines of the bottom of the structure to be built therein. Materials excavated for highways or rights of way, and for miscellaneous purposes for which measurement is not otherwise specified, shall be measured in place, to the limits established by the Engineer for each case. Payment shall be made for those parts only of such excavations which are outside of the prescribed limits for the regular aqueduct trench as above specified.

Cover Embankments. Section 16.1. " Under Items 16 to 29 the Contractor shall build cover embankments generally over the aqueduct wherever not in tunnel; foundation embankment for about 800 feet of aqueduct; embankments for highway changes, for rights of way and numerous minor purposes. He shall surface such public highways as are required, do miscellaneous grading in connection with the final surface drainage scheme, and shall refill trenches and other excavations as required. Embankments and refills will, in general, be made of earth from excavations under Items 2 to 15, but rock fills may be required or permitted, and materials for portions of the embankments may be taken from borrow-pits, subject to the provisions of Section 16.2.

Fills. Section 16.5. " All earth deposited in refilling and embanking below a plane 5 feet above the lowest point of the inside of the aqueduct, and inside of vertical lines 25 feet each side of the center line, shall be in horizontal layers not exceeding 6 inches in thickness after solidification, and each layer shall be sufficiently watered and thoroughly compacted. Above this plane and beyond these lines, rolling or ramming will not be required. Any settlement or sliding of materials below the designated embankment lines, whether due to lack of rolling or to any other cause, shall be repaired at the Contractor's expense before the completion of the contract.

Foundation Embankments. Section 16.6. "All aqueduct foundation embankments, below a plane 2½ feet above the lowest part of the inside of the aqueduct and inside of vertical lines 25 feet each side of the center line of the aqueduct, shall be built with extreme care with carefully selected earth. All stones larger than 3 inches in diameter shall be thrown out. The materials shall be deposited and spread in horizontal layers which will not exceed 3 inches in thickness after rolling, and each layer shall be sufficiently watered and rolled with a heavy grooved roller to thoroughly compact and solidify the materials. When directed during the construction, and if required, three times after the completion of the embankments, this portion shall be so thoroughly saturated that water will stand upon the surface. The building of the aqueduct upon such foundation embankments shall not be begun until they have stood at least six weeks after completion, unless otherwise directed.

Haul. Section 30.1. "The surface of refills and embankments, the slopes of excavations and any other earth surfaces, wherever and as ordered, shall be dressed with top-soil of the thickness directed. The Contractor shall not be required to procure top-soil from beyond the limits of the City's lands, nor to haul top-soil more than 3000 feet, excepting as provided in Section 1.2, nor to provide top-soil for a greater thickness than 12 inches.

Top-soiling. Section 30.3. "Surfaces prepared in accordance with Section 30.2 shall be dressed with an acceptable fertilizer in the proportions directed, and shall be sown with first quality grass seed of an approved mixture. If required, the seeded areas shall be watered at such intervals as directed, until the grass is well started. Grassing shall be done immediately after the preparation of the earth surface for which it is ordered, unless other directions are given. If there be any delay for which the Contractor is responsible, during which weeds grow on the surface to be grassed, or the soil is washed off, he shall remove the weeds or replace the soil without compensation. If any portion of the seeded areas are not thoroughly covered by grass they shall be refertilized and reseeded.

Settlement of Embankments. Section 30.2. "In general, top-soil shall not be deposited until, in the opinion of the Engineer, any refill or embankment upon which it is to be placed shall have approximately reached its final condition of settlement, or until satisfactory provision shall have been made for possible future settlement. Wherever necessary, in the opinion of the Engineer, the surface upon which top-soil is to be placed shall be raked or otherwise satisfactorily prepared to insure a proper bond.

Order of Work. Section 31.26. "The provisions of Section 18 relating to the order of doing the work shall be closely followed. In placing the concrete in the aqueduct section, the invert shall be built in sections not over 15 feet long unless otherwise directed, with a keyed joint between adjacent sections, substantially as shown on Sheet 9. The construction of the key blocks for this joint shall precede the placing of the concrete for the rest of the invert by at least such time as directed. Especial care shall be taken to obtain a smooth and true top surface parallel to the inside of the invert, on each key block, and unless otherwise directed, the top of each block shall be coated with cold-water paint, asphaltum or other approved inadhesive substance or lubricant. Unless otherwise ordered, pockets shall be left in the top of the concrete at each of the invert joints for the proper bonding of the expansion-joint of the upper portion of the aqueduct to the invert. The portion of the aqueduct above the invert shall be built in sections of some multiple of the length between invert joints, but in no case exceeding 75 feet. Any section once begun, whatever its length, shall be completed by the continuous laying of concrete, except that the Contractor will take approved measures to secure a good bond, to build the portion above the invert in two operations, provided that the division between the two does not occur at a greater height than 8 feet above the lowest part of the inside of the invert. The portion of the arch above this 8-foot limit shall be built, in any case, by the continuous laying of concrete.

Testing of Aqueduct. Section 39.1. "Portions of the aqueduct in open cut and on embankment, aggregating not more than 15 per cent of the total length of such aqueduct included in this contract, shall be tested for water tightness.

Hydrostatic Test. Section 39.2. "The testing of a portion of the aqueduct will be conducted in general as follows: The bulkheads having been placed and made water-tight, the Contractor shall fill the portion with clean water to a designated level. The water shall be maintained approximately at the designated level for purposes of observation until such time as a change of level is ordered. The testing shall be continued with the water at as many different levels and for such lengths of time as may be required, but the total time for any one portion shall not exceed 30 consecutive calendar days after the filing of the first designated level or after the completion of approved repairs, if any are required, in accordance with Section 39.6. The Contractor shall provide adequate means for drawing off the whole or any part of the water at any time, in such manner as to avoid damage to the aqueduct, its appurtenances, or adjacent property."

Grade Tunnel. Contract 11 contains the usual provisions covering work in grade tunnel. These will be more fully discussed under Contract 12.

First Season's Work. Work on this contract was started within a few days of notice to begin work and vigorously prosecuted during the remainder of the year (1908). It was planned to bring in all plant materials over the Ontario & Western R. R. at High Falls. A tract of level land above the railroad station was secured, and used as a yard connecting with the main line by a long siding with a good grade. Alongside of this siding were constructed a cement shed, storehouses, derricks and so on, and from it branched a long trestle for storing and loading coal into wagons and cars. This yard proved to be very convenient, and an improved highway was constructed from it to the line of the aqueduct.

Improvement of Highways and Use of Traction Engines. The contractor's superintendent had considerable experience in constructing State roads, and the requisite plant, consisting of portable crushers and road rollers, were available. Some of the roads were straightened in grade and line, stone walls being used to form a Telford base upon which were placed layers of crushed stone and stone dust, which were rolled; this gave an excellent roadbed, in some respects superior to the State roads, inasmuch as it was founded upon an old hard country road rather than fills. In this manner 3 miles of road were macadamized, and upon them four Buffalo-Pitts traction trains were in daily operation hauling supplies and materials. These trains did excellent work, and proved capable of keeping the work well supplied for the first season.

Excavation of Top-soil, etc. The first contract work consisted of clearing and stripping top-soil over the entire line. After the trees were cut, the top-soil was removed by drag or wheel scrapers and stored in neat piles alongside the right of way for future use to cover embankments previous to grassing.

Moving Steam Shovels over Public Roads. Later, six shovels were transported over the roads to the site of the work, and by December all of them were in operation. At first, the work of transporting the shovels over the road was very expensive, as they were hauled over a track laid just in advance of the shovels, of cross ties and rails loosely spiked, the track at the rear of the shovel being taken up and relaid in advance. Later, the cost of this work was considerably lessened by using rails spiked to longitudinal stringers, the rails being held to gauge by stiff cross-bars hooked to eyebolts in the timbers, these bars being readily taken off and replaced.

A still better and far cheaper method was later developed. Special, very wide wheels were fastened to axles and substituted for the usual flanged wheels. These axles were turned so as to fit the regular journal boxes. When they were in place, the shovels could be readily hauled over the roads by traction engines, two or more being used. The traction engines were Buffalo-Pitts, and the shovels 20- and 60-ton Marions.

Method of Excavation. A 20-ton shovel was put at each side of the Peak tunnel to excavate the portal cuts, other shovels being used to make first cut within 8 feet of subgrade. The contract prohibited excavated material to be taken off city land, so that it would be available later on for the cover embankment. Though it did not expressly so provide, it was expected that excavation would be made just in advance of the concrete arch and immediately used to cover it. The contractor, acquiring for a small price several farms adjacent to the city land, thought from his previous experience on heavy railroad construction that he could more economically prosecute the work by wasting or spoiling the excavation from the aqueduct trench and later securing the embankment material from borrow pits of suitable material on his own land.

The contractor proposed to make the first cut within 8 feet of subgrade along the entire line of the aqueduct, with the exception of points of deep rock excavation. The material from these cuts was to be cast partly on the downhill side to make a berm upon which narrow-gauge tracks were to be laid, later to be used for the transportation of concrete, etc. The material not necessary for this purpose was to be spoiled in some cases immediately adjacent to the aqueduct, and in others somewhat removed. Before this method could be formally approved, it was necessary to secure a modification of the contract to the extent of deeding over the contractor's land to the city for the life of the work. It was feared that if this were not done, in case of the failure of the contractor and the sale of these lands, the city would be left without sufficient earth to cover the concrete arch. It was also specified that the contractor was to leave the spoil banks and borrow pits in a presentable condition where exposed to public view.

For the first season the steam shovels made very good progress, and it seemed that this method would be successful.

When the steam shovels had completed the portal cuts of the Peak tunnel, a start was made in the tunnel, using steam. It was originally proposed to handle the muck of the tunnel bench by 20-ton steam shovels, using a special very short boom. It was found that these shovels could not work in less than the narrow section required—16-foot tunnel 18 feet high by 15 feet wide to C line.

Electric Power. It was planned to operate mixing machinery, compressors, etc., by electric power obtained from Honk Falls, where there was a hydro-electric plant sending current over a 33,000-volt line to Kingston and Poughkeepsie.

Water Supply for Contract. A small mill pond was acquired from which a 6-inch water line was laid to the aqueduct. From this point a 4- and 2-inch line ran through the length of the contract. This gave a gravity supply at a head of 100 feet, but due to the numerous bends and crooks in the wrought-iron pipe line, there was but little available head a few miles from the pond. To reinforce this supply in times of low water, a pumping station was installed on Esopus Creek, which pumped directly into the pipe line.

Work Accomplished During First Year. During 1908 the force averaged 356 men, with a maximum of 750 in December. These men were housed mostly in two camps, one at Atwood, accommodating 300 men, the other at south portal of Peak tunnel, accommodating 200. Considerable progress was made in excavation, and several large concrete culverts were built, the portals of the Peak tunnel excavated, a large storage yard containing many buildings established, several miles of road rebuilt and a great deal of plant brought in.

Compressor Plant. During the second year, 1909, a high-tension transmission line was built from High Falls to the south portal of the Peak tunnel. An electric compressor plant was here installed, consisting of two belt-driven Laidlaw-Dunn-Gordon two-stage compressors, each of a capacity of 1530 feet of free air to 125 lbs. pressure. Between the high- and low-pressure cylinders an inter-cooler was provided; the motors were 250 H.P. at a constant speed 517 revolutions per minute. Across the Peak a 6-inch wrought-iron screw-joint pipe line was laid to the north portal and later on extended 2½ miles further to Atwood, where two steam shovels and several drills were operated at times by compressed air from this power-house. The line was also laid southward, operating steam drills, hoist, etc. It was found that a steam shovel could be very efficiently operated by compressed air, and with considerable economy, when the shovel was in a place to which it was difficult or expensive to haul coal.

Peak Tunnel. During 1909 the work of excavation of Peak tunnel was vigorously pushed, as it was highly desirable to secure the

Plate 64.—View of South Portal of Peak Tunnel, Looking from Interior of Completed Cut-and-cover Aqueduct.

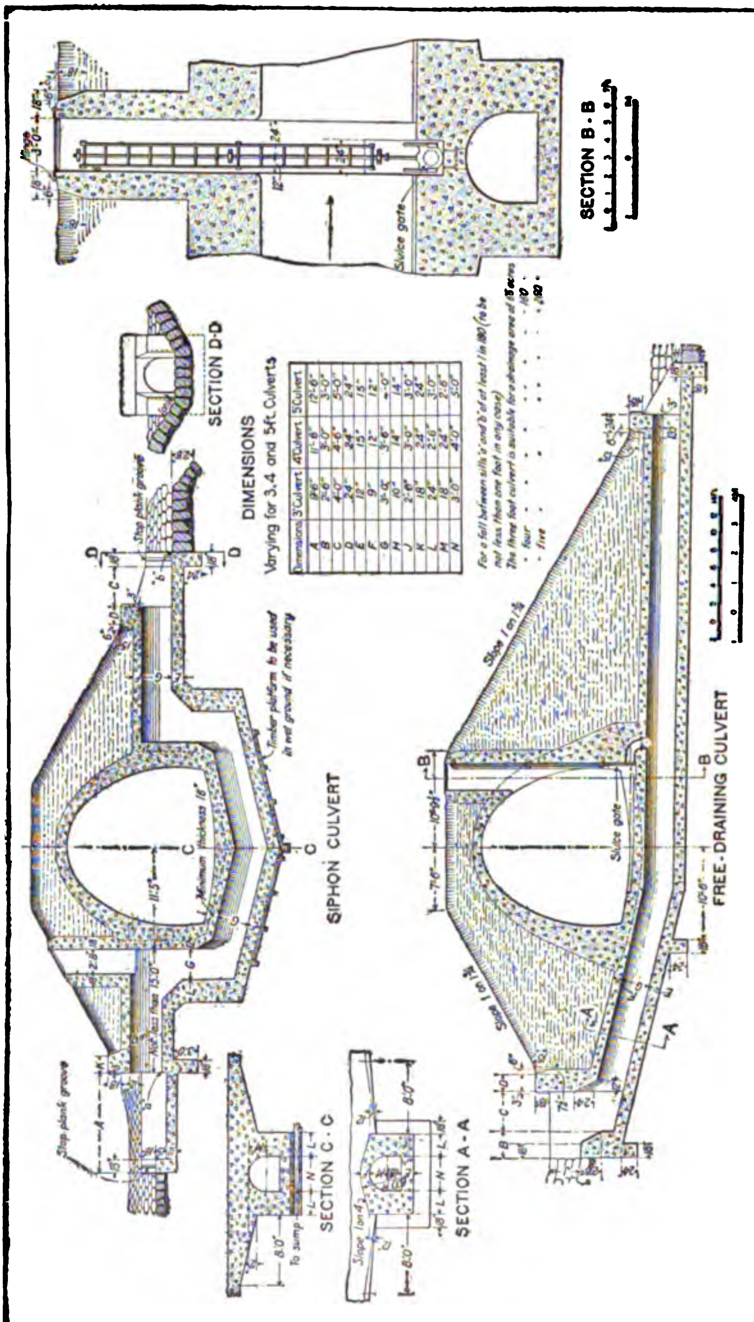
use of this tunnel for a railroad track, giving direct communication with the north end, otherwise reached by a tedious and difficult country road. The rock was firm Hamilton shale underlying a bluestone layer; it was easy-drilling and stood up well without support, requiring only three short stretches of timbering, one inside at a fault, the other two at the portals. The ordinary top heading and bench method was used, and an average progress of about 240 feet per month per heading made. Mucking of the bottom was greatly handicapped by use of 4-cubic yard side-dumping cars intended for steam shovel use. Headings met on Oct. 27, 1909, the Peak tunnel being the first one of a long series of tunnels in the Catskill Aqueduct to be completely excavated.

Tunnel Section Obtained. The top heading was usually driven to a good line and section, particular pains being taken by the engineers to secure this, but there was a decided tendency to leave the bottom half narrow, with one or more feet of solid rock above subgrade. This was due largely to rivalry between two superintendents on different sides of the tunnels in an endeavor to excel one another in progress. Also, in the wet portions, there was a tendency to run up to keep the tracks dry. Later, the trimming of this tunnel proved to be rather expensive, showing that it would have been cheaper to have driven more carefully from the start.

Trimming of Bottom and Laying of Drain. A very good method of trimming the hard bottom was developed and used in conjunction with the laying of the subdrain. Holes were driven from drills mounted on a car running on a track through the tunnel. These holes when shot and mucked out formed a trench in which a wooden box drain was laid. Toward this drain trench the remaining bottom was shot after holes were drilled along the side walls of the tunnel, the drain meanwhile very efficiently carrying off the water.

Side walls of the tunnel when tight were drilled from a platform car running on the center track. Later, concrete footing courses were laid at each side wall to an accurate line and grade. Upon them a templet was mounted, supported by a small trestle on wheels. This templet was carefully run through the tunnel, and all rock necessary to be taken down before concreting removed. The final result was a tunnel trimmed very close to line and one in which rapid progress was made in concreting.

Construction of Culverts. During the second year, 1909, aside from installing a compressor plant and excavating the Peak tunnel, as previously described, not much progress was made. North of the Peak tunnel, the only concrete work consisted of the building of culverts. The plant used for building culverts consisted of derricks, a Smith mixer, and small portable road crushers. This work, although conducted at a loss, was of great help later on during the construction of the aqueduct, as it saved delay which otherwise



Dimensions	3' Culvert	4' Culvert	5' Culvert
A	9'6"	11'-6"	12'-6"
B	2'-6"	3'-0"	3'-0"
C	4'-0"	4'-6"	5'-0"
D	24"	24"	24"
E	12"	15"	15"
F	9"	12"	12"
G	3'-0"	3'-6"	4'-0"
H	10"	14"	14"
J	2'-6"	3'-0"	3'-0"
K	18"	24"	24"
L	24"	2'-6"	3'-0"
M	18"	24"	2'-6"
N	3'-0"	4'-0"	5'-0"

PLATE 65.—Designs of Small Culverts for Catskill Cut-and-cover Aqueduct.

would have ensued at each culvert and made the drainage much better, particularly in the wet sections, where as soon as shovels had excavated to subgrade, box drains were laid below invert level, leading to culvert where they would freely drain.

Traveling Concrete Plant. South of the Peak tunnel some aqueduct was built, but mainly for the purpose of trying out a novel concreting plant. After a few hundred feet of invert and a short section of arch were concreted by use of a temporary plant and derricks, the new steel plant was erected. The main portion of this consisted of a three-deck steel structure built on two large steel cars bolted together side by side. These cars were 60 feet long and ran on rails fastened to large wooden ties cut to fit the curve of the invert. On the upper deck of this traveler was fastened a revolving electric crane with 40-foot boom, designed to lift the concrete materials from cars running on a track alongside to various bins and platforms on the traveler. Onto one of these platforms, skips of stone were dumped by the electric crane and fed into a No. 4 McCully gyratory crusher from which a 25-foot bucket elevator raised the stone to a revolving screen. The rejects from this screen were fed to a gyratory crusher, No. 2, which in turn fed to flat sand rolls, and thence to the bucket elevator, where the revolving screen allowed it to pass to the sand bin. Natural sand was used to a minimum amount of 50 per cent and stored in the sand bin, reaching the bin either by being fed through the stone crusher or directly by buckets. Underneath the stone and sand bins were placed the four measuring hoppers of the Hains gravity mixer, and below this the various Hains mixing hoppers. From the rear end of the traveler a steel bridge was pivoted. This bridge had a span of 110 feet, resting on a small steel tower, which was mounted on wheels running on a track supported by steel saddles made to fit the top of the arch.

Electric Telpher for Concrete Buckets. Attached to the lower chord of the bridge was an I-beam upon which an electric telpher was operated. This telpher contained a little car in which the operator was seated, and was moved by traction wheels. He operated an electric hoist which raised and lowered the concrete buckets charged from the Hains mixer. These buckets were run directly over the forms by the operator and dumped by men who standing on the forms placed and spaded the concrete. The designer, Mr. Longnecker, aimed at a self-contained traveling concrete plant, complete in every particular, which could not only mix the concrete, but could also crush the stone and make sand, and in addition move the outside forms. For the latter purpose a traveler was erected on the top of the bridge and was operated by a chain hoist.

Method of Moving Plant. The plant was to move itself longitudinally by an electric-motor operating chains to the axles of the car much as a steam shovel moves, but this did not appear to work well. However, it was found that the plant could easily be moved by a dinky engine hauling over a rope attached to blocks fastened to the ties and to the plant. The saddles were in the rear of the bridge and were elevated by a chain hoist attached to an I-beam on the rear tower, turned 90°, hauled through the tower, and deposited parallel to their original position, each saddle containing 5 feet of track. All the machinery on the plant was electrically operated, power being obtained from a transmission line paralleling the aqueduct.

Troubles Experienced with Traveling Plant. As might be expected from such a complicated system of machinery, placed in new conditions, trouble was experienced in getting the plant to work smoothly. It was found that the electric revolving hoist had not sufficient capacity to raise the necessary material for concreting a 30-foot section in eight hours and heated up badly. This was remedied by fastening a small air- or steam-operated stiff-legged derrick to the framework of the structure. This derrick, operated by hoists, raised stone and sand, the electric hoist then being largely used to elevate skips of cement to charging level of mixer.

First Blaw Aqueduct Forms. The first installation of Blaw forms on the Catskill Aqueduct was used here. The interior forms were designed to collapse and telescope. The outside form was of steel panels bolted together in a large number of units. This form gave considerable trouble, as it was lacking in rigidity. This was remedied by the use of stiffening angles. The panels were riveted together so that they could be handled in 5-foot sections the full height of the form. The interior form was found to be rather weak, the plates and interior bracing being light. The interior forms were collapsed and moved on a wooden A-frame operated by hand-jacks. The form contained three hinges, at the top and at the sides near the bottom, the bottom panels being folded inward before dropping the form to position, when it could be passed forward through the forms set up for concreting. All the curves in this contract being planned to a 200-foot radius, the inside and outside forms were cut wedge-shaped, so that when turned they would approximate a 200-foot curve with chords of 5 feet on the center line. In passing from a tangent to a curve, or vice versa, every other 5-foot section would be turned 180° by means of a turn-

PLATE 66.—Contract 11. Body of Traveling, Crushing and Concrete Plant. Wooden Derrick was Air-driven and Raised Stone to Crusher. Steel Electric Derrick Raised Sand and Cement.

PLATE 67.—Contract 11. Traveling Crushing and Concrete Plant, Showing Saddles at Rear of Bridge and Bridge with Overhead Traveler for Moving Outside Forms.

table upon which the A-frames carrying the forms were mounted. This feature did away with the necessity of inserting fillers on the curve, and was designed to save time and to give smoother work.

Performance of Plant During First Year, 1909. The traveling plant succeeded in placing 2150 feet of completed aqueduct from August to December, the best month's progress being 485 feet. This was considerably less than the planned progress of 30 feet of completed aqueduct per working day. During the first operation of this plant the concrete for invert, after being mixed in the Hains mixer in the usual way, was run through to the front end on a long belt feeding into cars which were pushed by hand on rails to the invert block being placed. It was found difficult to feed the belt at the proper rate, and a great deal of wet concrete was spilled. Later a locomotive crane was used to load buckets on cars running on the bank, whence they were pushed by dinkies and dumped over the bank to the invert.

Method of Building Invert for Cut-and-cover Aqueduct. During this year key blocks were constructed at 15-foot intervals. These were cast between steel forms; on them other 8-inch steel forms were placed to the grade of the aqueduct, and alternate blocks of 16-inch invert cast to 32 feet 4 inches radius. The key blocks were for the purpose of producing a water-tight joint and to facilitate the laying of the invert to exact grade. At first screed boards were used between the invert forms. These boards required considerable manipulation and labor to get the concrete in proper shape for troweling.

A solid steel shaft, turned down at the ends, so that long handles could be fastened at right angles to the shaft, was then used. The shaft, after the concrete had set a little, was rolled on the forms, beating down the stones and shaping the concrete to proper grade, and leaving it in such condition that little troweling was necessary. This shortened the time for forming the invert and also gave a better finish to the concrete. This shaft had such obvious merit that it was universally adopted by the contractors, and it should be applicable to other similar classes of work.

Expansion Joints at Bulkheads. At the end of each day's work grooves were cast which formed tongues of concrete when the adjacent sections were deposited. As the concrete changed in temperature this acted as an expansion joint, designed to prevent leakage. At first cast-iron blocks with a draw of $\frac{3}{8}$ of an inch in 5 inches were used for forming the groove. These were found unwieldy, so that eventually solid seasoned oak blocks were used for this purpose,

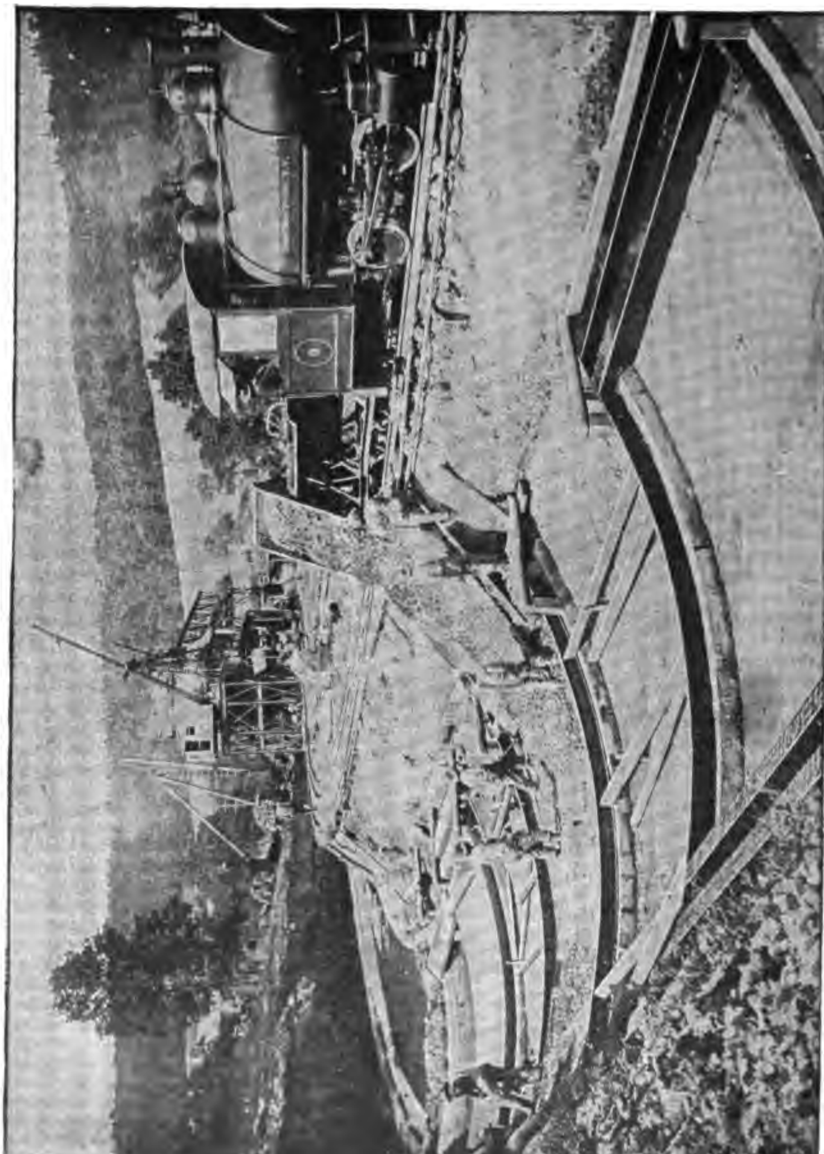


PLATE 68.—Contract 11. Connecting Invert of Cut-and-cover Aqueduct. Concrete Hauled from Traveling Plant by Locomotive. Key Blocks and Steel Invert Forms in Place.

these blocks being bolted to the steel bulkhead forms separating the inner and outer arch forms.

Steaming of Concrete at Bulkheads. During the cool weather it was found that unless several days were allowed for the concrete to set, the pulling of the bulkhead forms with the blocks would tear the concrete, so that poor expansion joints were formed.

As the plant required the concrete arch to be cast in contiguous sections, this was a considerable handicap until a steam radiator was devised. This was formed of two pipes roughly curved to the shape of the aqueduct resting on the projecting inside form. Over this was cast some canvas, so that when the steam was turned through the radiator, the face of the bulkhead would be heated. In this way it was found that the bulkheads could be pulled in a few hours, giving clean-cut grooves and corners. The steaming of the joints cost very little, as the dinky engines idle through the night were used. It would seem that steaming forms to enable them to be pulled quicker might save many delays in construction work, particularly where steel forms are used. Steel forms cool off concrete much faster than wooden ones, the angles of a panel form particularly helping radiation, acting much as the fins cast on the cylinder of an air-cooled gasoline engine.

Concrete Tongue vs. Steel Plates. Contract drawings allowed the use of either the grooved or steel-plate joint at the ends of the day's work. The contractor elected to use the grooved joint, as they deemed it less troublesome than the other. Upon testing some sections of the aqueduct during the winter, it was found that the concrete tongue-and-groove joint was liable to leakage, the tongues occasionally being sheared off in the grooves. It was thought by carefully casting the grooves with a liberal draw and painting them with asphaltum this would be prevented, but broken joints were found in the best work. Some other contractors elected to use the steel plates, and an examination of these sections during the winter of 1910–11 showed that they were less liable to leakage, so during 1911 all joints were cast with steel plates in the bulkhead. These plates are 6 inches wide and $\frac{3}{8}$ inch thick, covered with asphaltum and placed in a groove in the bulkhead so as to project about equally into adjacent sections of arch. See Plate 74.

Substitution cf Steel Plates at Invert Joints for Key Blocks. Examination of the invert also showed that the key block joints were leaking somewhat, and it was decided to eliminate them, casting the invert with square ends in which were inserted plates similar to those in the arch joints. This change of method was very agreeable to most of the contractors, as key blocks were troublesome to cast, especially where the invert was wet, and as the whole bottom could not be excavated to final grade previously to placing the invert, shallow cross-trenches had to be dug for the key block forms. These tended to fill with water and had to be individually pumped out. By eliminating the key blocks the bottom could be graded off and the invert cast in one piece. The superintendent for Contract 11 estimated that 50 per cent more progress could be made in laying invert without the key blocks, and at the same time fully as good work obtained and with tighter joints.

Hains Derrick Mixer. An effort was made to concrete culverts with the Hains derrick mixer. This mixer was supposed to be the simplest made, composed merely of three or four conical buckets, each equipped with small double doors opening downwards. The buckets are connected by chains on the outer perimeter. The concrete material is placed in the top bucket, properly proportioned. The buckets rest one within the other. The derrick hook is fastened to a cross chain on the upper bucket and elevated slowly. This lifts the buckets one after the other, the doors opening by gravity, letting the concrete through. While the derrick is swinging to the place where the concrete is to be deposited the concrete passes through all the buckets and is deposited in place mixed. This device is economical where small quantities of concrete are to be deposited by a movable plant. Unfortunately, although every effort was made to get a good mix, it seemed impossible to get uniformly good results; an occasional batch would be very well mixed and others very poorly, so that the contractor was forced to abandon this device.

Management of Contract 11. During the first two seasons, the superintendent at the work reported to the board of directors of the Stewart-Kerbaugh-Shanley Company. Early in 1910, the work was placed solely in charge of H. S. Kerbaugh, to whom the superintendent reported till its completion in 1912.

New Blaw Forms. The Blaw forms used during 1909 were sent away and new forms substituted. These forms were designed in the office of the contractor, and although on the general lines of the usual Blaw forms were much heavier, being composed of $\frac{1}{4}$-inch plates braced by heavy ribs, and horizontal angles dividing the form into small stiff panels. The inside forms were jointed in three places and designed to be used telescoping. They were built wedge-shape to form tangents of 200-foot curves as previously described. Both inside and outside forms were in 5-foot sections. These forms are shown on Pl. 69. They were built in the shops of the Blaw Company and rented to the contractors, as is customary.

Electric Carriage for Moving Forms. Considerable difficulty was experienced with the first Blaw carriage used for moving the interior forms which led Mr. Kerbaugh to construct three electrically operated carriages. These were built entirely of steel, operating on 5-foot 9 inch gauge track running on the invert. The base of it was a stout steel car propelled by gearing, much in the same way as a locomotive crane. On this car was mounted a turntable which supported an A-frame and a platform containing the motors. These motors operated several large screw-jacks and propelling mechanism. The vertical screw-jacks raised and lowered the forms. There were also several horizontal jacks, hand operated, to pull the forms in and out. The bottom lids were raised and folded inward by cable and winch on car. This electric carriage was successful and much facilitated the moving of the forms. By its use a few men could collapse and set up in a new position about 60 feet of form in eight hours. This carriage is shown on Pl. 70. It is doubtful, however, whether the work requires such an elaborate carriage, as some of the other contractors were able to move about the same amount of form with a much simpler hand-operated outfit, using perhaps a few more men in the operation.

Improvement of Steel Traveling Concrete Plant. The steel traveling plant with bridge previously described was much improved, the overhead bridges being lengthened from 110 to 140 feet and in place of the hand-operated chain hoists, electric chain hoists were substituted. This greatly facilitated the moving of the heavy saddles, which previously had been a slow and tedious operation, seriously delaying moving the plant. Electric hoists were also placed on the traveler operating on top of the bridge which moved the outer forms, and also helped to considerably shorten the time for moving the outer forms. In addition a new electric traveler was ordered for the concrete, but this was not put into use until late in the year. The size of the measuring hoppers was increased to accommodate eight bag batches of 1–3–5 concrete.

Concrete Plant for Invert. Experience of the previous year showed that it was impracticable to try to place invert and arch at the same time with the concrete supplied by this plant. To supply concrete for the invert a small plant at the south portal of the Peak tunnel was used. The concrete was proportioned in hoppers and dumped dry into Hains bottom-dumping buckets and hauled on flat cars, by dinkies, to a traveling plant at the invert. This

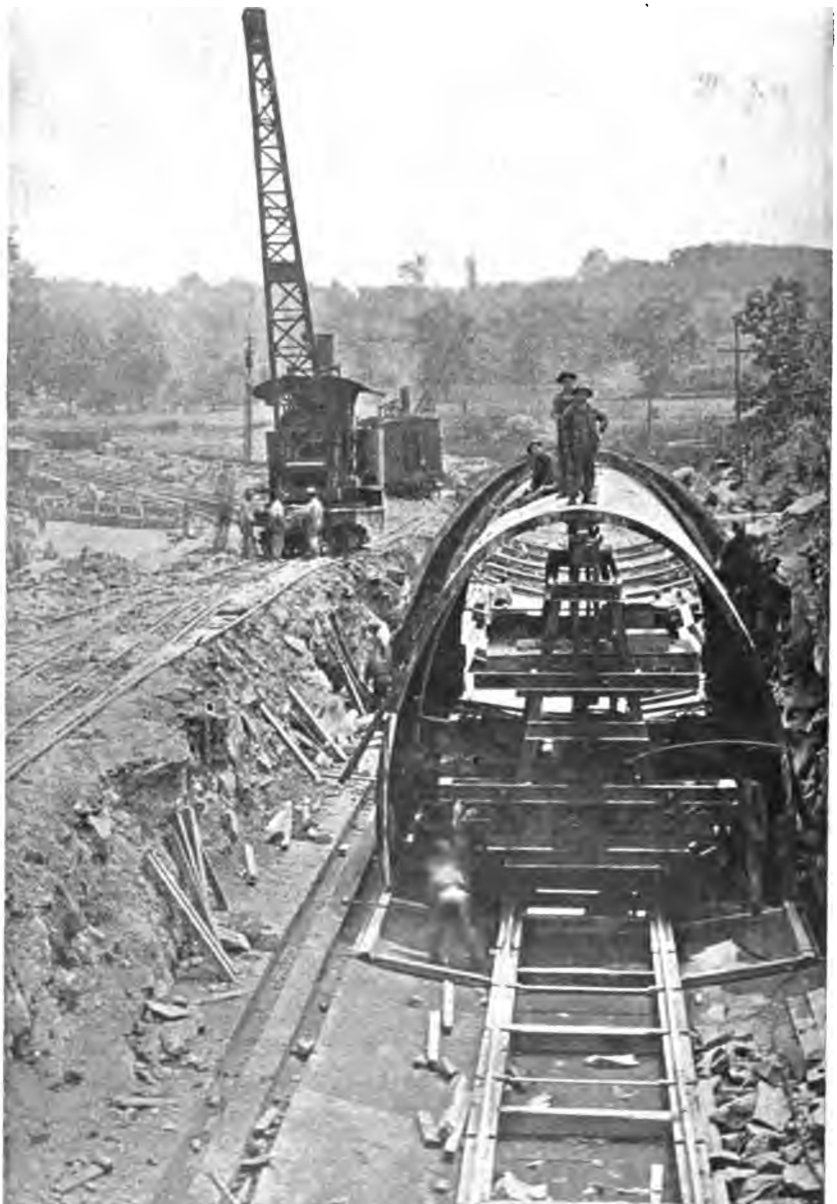


Plate 69.—Contract 11. Construction of Cut-and-cover Aqueduct on Section 1. Shows Steel Form and Carriage; also Locomotive Crane Used to Place Concrete, Move Outside Forms, and Assist in Excavation.

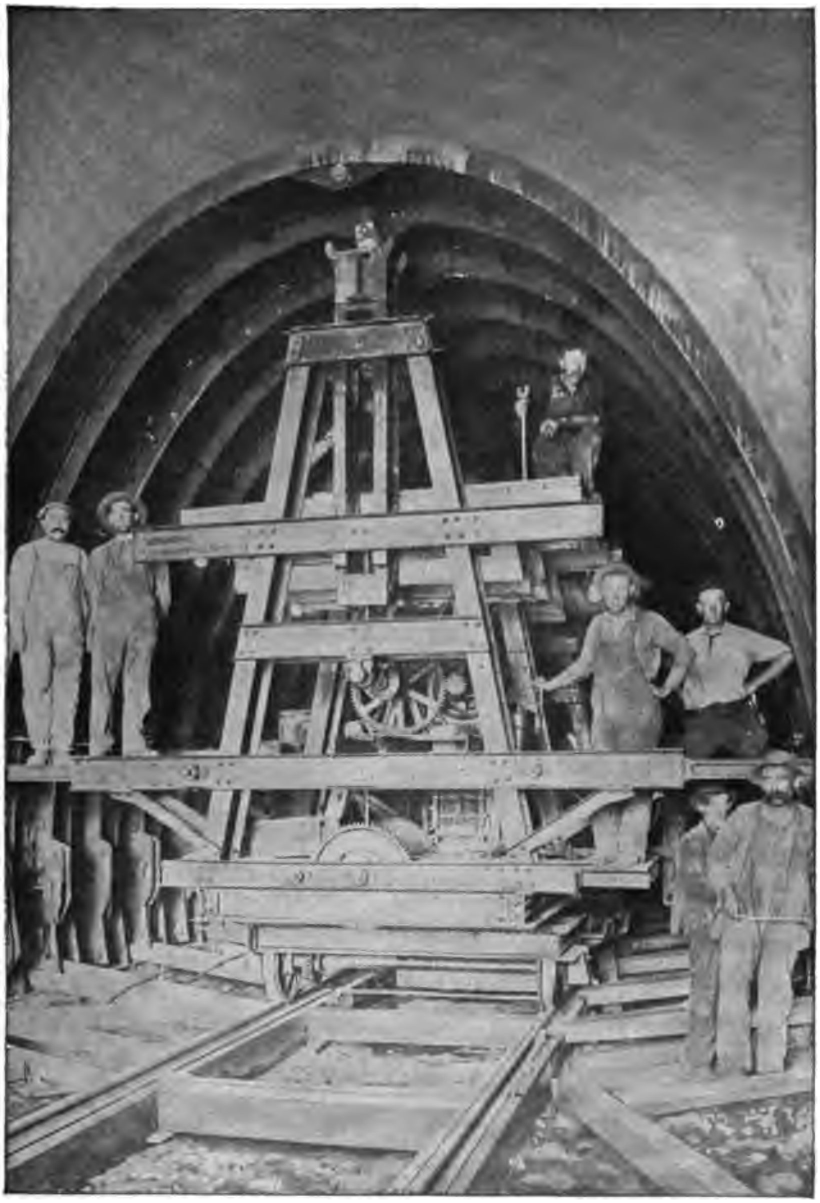


PLATE 70.—Contract 11. Electric Carriage for Moving Interior Forms for Cut-and-cover Aqueduct. Carriage and Upper Jacks are Motor Driven. Side Jacks and Turntable Hand Driven.

plant was constructed on a platform spanning flat cars, the main parts being a small derrick and a Smith mixer. The derrick picked up the buckets, dumping them into the mixer, which in turn emptied into a chute directly into the invert. The mixing plant operated on a narrow-gauge track close to the edge of the cut. This plant was found to be very efficient and readily placed at night 60 feet of invert.

Operation of Traveling Plant during 1910. The large traveling plant was left free to make arch in the daytime, and at this it was very successful. Stone from the Peak tunnel was excavated from the spoil bank by a 20-ton steam shovel loading onto wooden skips placed on flat cars. Parallel to the trench on the downhill side was a double narrow-gauge dinky track. The skips were lifted from the flat cars by a wooden stiff-legged derrick. Cement and sand were elevated by the electric hoist. As soon as a stretch of 45 or 60 feet of arch had been concreted, which took about eight hours, the outside forms were moved forward; also the saddles, the plant being hauled by the dinky engine. During the night the inside forms were moved, the invert concreted, and everything put into readiness for the next day's work. The plant maintained a rate of 45 feet of completed aqueduct per day for forty-one consecutive days, and 60 feet per day for the next five days, without any breakdown or delay. From May until October the plant concreted about 5400 feet of arch. After reaching Shaft 1 the plant was dismantled and removed from the work. The Browning locomotive crane was used to move the saddles upon which the plant traveled and to assist it in other ways. It also operated a grab bucket for trimming invert.

Comparative Success of Traveling Concrete Plant. The traveling plant described fulfilled its guarantees, as the designer at first built it only to construct 30 feet of aqueduct per day, and it finally proved capable of doing 45 and 60 feet, although it was not successful in building invert at the same time. The contractor expressed himself as being well pleased with the operation of this plant, although he later developed a method, by the use of stationary mixing plant and locomotive cranes, of constructing aqueduct more cheaply, when the heavy first cost of the traveling plant is taken into consideration. This plant probably cost from $30,000 to $40,000, including the cost of alterations, which had to be charged up to only 7000 feet of aqueduct.

Excavation of Firm Earth Section by Steam Shovel. Remarkable work was done by a 60-ton steam shovel which excavated the lower 8 feet of cut in advance of the traveling plant. This shovel excavated

PLATE 71.—Contract 11. Traveling Crushing Concrete, Mixing, and Form-moving Plant Completing Last Section of Aqueduct Adjoining Shaft 1 of Contract 12. This plant built 7500 feet of aqueduct in two seasons.

to the close lines of the aqueduct in firm earth, with bottom width of only 20½ feet with 6 on 1 slopes. The shovel was able to excavate to close lines on both curves and tangents, leaving its tooth marks on the firm hardpan in almost exactly the correct lines. All that remained was a little of the invert to be shoveled into piles excavated by grab buckets operated by locomotive crane. The shovel loaded directly in 4-yard dump cars, which were hauled to the uphill side of the excavation and dumped directly into the embankment over the completed aqueduct a few hundred feet behind the traveling plant. This disposed of the excavation in an ideal way, and the contractor was paid for excavation and refill at the same time. Well-shaped embankments were immediately obtained. This is probably the longest stretch—about 6000 feet—of firm or compact earth section on the Catskill aqueduct. The saving is about $10 a foot over the loose-earth section, type A. In most other localities it was found difficult to excavate to the close lines of the type B excavation, the sides not standing up sufficiently well to enable the concrete to be placed directly against them, so that excavation lines in whole or in part had to be widened to the maximum section, although by provisions of the contract payment lines were maintained to the 6 on 1 slope.

Plant North of Peak Tunnel. Entirely new plants were installed north of the Peak tunnel. At a bluestone quarry adjacent to the aqueduct a large stationary Champion jaw-crusher plant was installed. This plant was supposed to be of large capacity, and was also equipped with sand rolls. While only a moderate amount of crushed stone was needed, this plant met the requirements, but later it was unable to keep up with the work and a large No. 8 McCully gyratory crusher was installed. The bucket elevator of this crusher discharged into the screens over the large bins, the jaw crushers merely taking the rejects. It was early found that the sand rolls could not stand up to their work, the rolling of the hard blue stone causing frequent breakdowns and heavy repairs. The ordinary crusher dust, however, was used mixed with fine natural sand obtained from a local sandbank. Near this crusher a large Hains mixing plant was installed equipped with the usual sand, stone and cement elevators. In addition, another concrete plant of this character was also installed on Section 1. (See Pl. 72.)

Excavation by Steam Shovels. Two 60-ton Marion steam shovels were installed at the junction of Sections 1 and 2, one working north and the other south, excavating the final cut. The standard booms were removed from these shovels and special long booms installed.

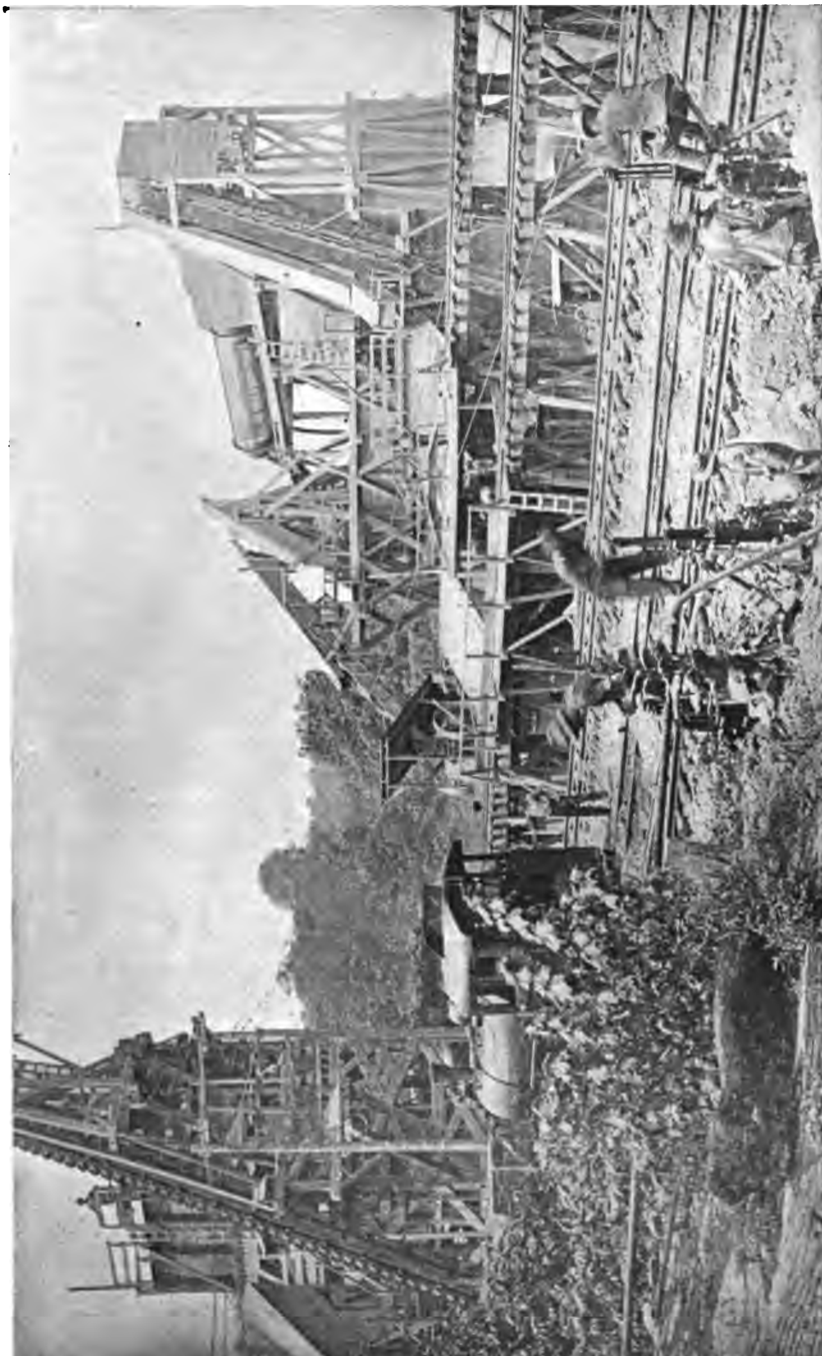


PLATE 72.—Contract 11. Main Crushing Plant for Two Upper Sections. Haines Concrete Plant. Drilling Trench in Advance of Aqueduct Construction.

These, although equipped with 2½-yard buckets, were able to place material in cars 28 feet from center of shovel and 17 feet above the rail upon which the shovels ran. They much facilitated the work, enabling the shovels to dig in one operation trenches which otherwise would have been excavated in two lifts. These shovels were able to keep ahead of the concreting and the earth cuts, but with great difficulty in the rock cuts, even though they worked two or three shifts.

Power to drive the drills for the rock cuts was obtained from a long compressed-air line from a plant at the south of Peak tunnel.

Concreting with Locomotive Crane. A double narrow-gauge track was laid close to the lower side of the aqueduct, and over it concrete buckets and excavated material were hauled. For concreting invert, a locomotive crane was used to swing the buckets from the cars into the cut, the invert being laid as previously described.

"Spacing Out" Method of Setting Arch Forms. On a stretch of completed invert about 380 feet of steel forms were erected, and after being concreted, one half was used northward on Section 1, and the other half southward on Section 2. These forms were designed to be used telescoping, but were employed in a different way, using the "spacing out" method as follows: Each length of, say, 180 feet of form, was concreted in three 60-foot sections, working from the forward end backward, using steel bulkheads to form the expansion joints at the end of a day's work. While the third section was being concreted, the first 60 feet of forms was run ahead 180 feet from its previous position and concreted while the two following sections would be placed adjacent to it, the third section of inside form closing the gap and overlapping by a few feet the concrete arch previously placed. By this method, the forms need not be telescoped, and therefore do not require much folding in and out, giving much greater flexibility. The forms can be moved in the daytime. Although the forms were made very heavy, it was found that they still deflected so as to cut into the waterway. This was remedied by the use of pipe braces in the ends of which were set hand-operated screw-jacks. On the upper sections electric carriages for moving forms were employed.

Details of Concreting and Handling Forms. After considerable experience on this and other contracts the following practice in concreting cut-and-cover aqueduct came to be nearly standard. After the invert was cast the forms were set up carefully on wooden sills, so as to give a waterway about ¾-inch larger all around than the theoretical. After being used, the forms were carefully cleaned of loose concrete with kerosene and greased with heavy oils or mixture of crude vaseline or Albany grease with kerosene or engine oil. In some cases the forms were cleaned with steam jets, but it was found that a light skim of cement on the forms when greased gave a good finish. The forms were internally braced to prevent undue movement while concreting; and inside and outside forms were tied together securely with taper bolts about three to a side, on 5-foot centers. To prevent cracking of the adjoining arch due to rising of the interior form while concreting it was found necessary to very securely brace the interior form with horizontal timbers where the form overlapped the adjoining concrete arch. Extra bolts between interior and exterior forms at the face of the old concrete also helped materially. The concrete (about 1–3–5) was brought up very wet in level layers, the depth being kept nearly the same on both sides of the forms. The concrete was dumped on top of the arch forms and allowed to flow or was pushed down the sides. Two or three men were kept between forms on each side to distribute and spade the concrete; when the concrete rose about half way they came out and worked from top. The top of inside form was regreased previously to covering with concrete, which was then mixed a little dryer to allow the proper shape to be obtained. Usually upon pulling the form a smooth finish was obtained, although there was considerable trouble at times with peeling and sandy streaks. The inside forms were struck by pulling in the sides and lowering. The bolt-holes in concrete were grouted by pouring with a thick grout, a little head being obtained by using a sort of clay swallow's nest at the outer end of holes. Upon test these holes were always found to be tight.

The arch was placed in the same manner as the invert, by the use of locomotive cranes and bottom-dumping buckets, the cranes being also employed to move the outside forms. The Hains bottom-dumping bucket, although it operated satisfactorily at the traveling mixing plant in Section 3, previously described, was found to be very troublesome when used to haul concrete any considerable distance. The concrete, arching in the bottom of the conical bucket, refused to come out even when the doors were wide open. This bucket was replaced by the Steubner bucket, which gave good satisfaction.

Transmission Line. The 33,000-volt transmission line was extended to the upper mixing plant and from it the current was transformed down to 2200 volts to drive the twin Champion crushers and to 220 volts to drive the other motors of the mixing, crushing plant, etc.

Failure of Hauling by Traction Engines. Strenuous efforts were made this season, 1910, to catch up with the required progress, and no stint was made by the contractor of plant, materials or men. The roads were improved and several new traction engines installed to operate trains and haul cement and material. The operation of the three concrete plants at the same time caused a great demand for cement which the traction engines hauled to the south portal, where it was reloaded on narrow-gauge cars and used at the three plants. Each traction engine was capable of hauling a flat car of 340 bags of cement. In dry weather they were barely able to keep up with the work, but on wet days the traction engines had to be doubled up to negotiate the heavy grades, although the road was well macadamized between High Falls and the Peak. The traction engines were continually ditching themselves in wet weather and tearing up sections of the best road, making heavy repairing necessary. The engines themselves were also constantly breaking down, keeping a large machine shop at Atwood going under high pressure and at very heavy expense. By the middle of the summer it became manifest that it would be impossible to keep the work going by the use of traction engines.

Construction of Connecting Railroad from High Falls. The contractor secured the rights of way for a narrow-gauge railroad from the High Falls yard to the south portal of the Peak tunnel, a distance of 4½ miles. To secure this right of way it was necessary for him to buy several farms outright, and the rights were very costly.

Great speed was made in the laying of this road, 4½ miles of track being graded and made ready for the trains in three weeks. The expense of building this road justified itself, as thereafter it was easy to supply the work with cement, coal, and other materials, the road taking the place of nine traction engines and about all the teams which could be hired in the neighborhood. It would seem from the experience that it would have paid the contractor to have laid at the beginning of the work the tracks connecting the O. & W. R. R. with all parts of the aqueduct line.

Standard- vs. Narrow-gauge Tracks. The contractor's superintendent is also of opinion that a standard-gauge track would have been far preferable to the narrow-gauge road, as the expense of unloading and transferring to the narrow-gauge cars would have been saved. In addition, the expense also of considerable number of small cars could have been saved, as cement and coal cars of the railroad could have been directly used. The steam shovels and locomotive cranes could have been taken at much less expense to the work over a standard-gauge track, and also from place to place on the work. It was often necessary, in taking a shovel from one part of the work, to another; to lay tracks over rough ground to the nearest road, jack up the shovel, place flat wheels under it, and haul it by several traction engines to a point near the aqueduct, and again lay a track up steep hills to get the shovel to its next working position. Standard-gauge locomotives are much more efficient than narrow-gauge, as also are standard-gauge cars of all types. It is estimated that a single standard-gauge track alongside the cut with proper switches could have taken the place of the double-track narrow-gauge line used. It was found that locomotive cranes were not stable on narrow-gauge tracks, and it was necessary to lay a third rail and intermediate ties to make a standard track for them to operate on. This would have also been saved by a standard-gauge track in the first instance. Standard-gauge equipment is also more salable and far more readily transferred from one job to another.

Excavating Rock Cuts during 1910. During this season it was found that the steam shovels could not keep ahead of the invert where rock was encountered, although every effort was made. The rock where suitable was sent to the crushing plant and used for concrete; otherwise it was either spoiled or used over the aqueduct. This caused a deficit of embankment material, and it was necessary to place shovels in borrow pits to furnish embankments for the required line. When a suitable borrow pit was obtained and track connections made embankments could be made very rapidly at a low cost, so that it paid to keep the shovels well in advance, rather than to delay the work, even though considerable material had to be spoiled.

Excavation of Rock Cut at Atwood. During the winter of 1910–11, the steam shovel was kept at work on a deep rock cut at Atwood Cliff, excavating it to subgrade in several lifts. A large quantity of this rock after being crushed was stored in a large stock pile. As the contract contained provision for advance payment on crushed stone of 80 cents per yard, this work not only paid for itself, but was an immense help in the following year's work, which would otherwise have been seriously delayed by this deep cut. A great deal of material excavated in this work was used in forming a high berm or fill at 8 feet above invert level. Upon this was laid a double narrow-gauge track. Invert and aqueduct through this stretch was thus constructed rapidly in the usual manner; otherwise it would have had to be constructed in through cut from one end, which is slow and expensive.

Progress During 1910. During the season of 1910 there were constructed on the three sections a total of 16,710 feet of aqueduct, bringing the work up to contract requirements. Nevertheless, the contractor was dissatisfied with the progress as compared with the expense.

Work above Tongore Creek. Above Tongore Creek was a stretch of 2973 feet of aqueduct cut off from the rest by a deep gorge. Nothing had been done on this stretch except to excavate and store topsoil, and it was given over to the firm of Cinedella & Gardetto, who installed a small central crushing and Smith mixing plant. The crushing plant was supplied with stone from a near-by quarry and from walls. The first excavation at the south exposed a great deal of sand which was stored and used throughout the contract. The contractor aimed to do the excavation by a very economical method, thinking that the amount did not warrant the use of steam shovels. Though an efficient force of laborers was employed, it was found that they could not load the skips and buckets fast enough to enable even 15 feet of aqueduct to be completed per day. A large traveling derrick and a locomotive crane were employed to remove and raise skips and to operate an orange-peel bucket, which in hardpan could make but slow progress. A narrow-gauge track paralleled the trench, and backfill was hauled over the aqueduct. Bottom-dumping concrete buckets were used for invert and arch, handled by the locomotive crane, which dumped the concrete by use of a second fall line. Buckets were Cockburn automatic self-dumping. Flat cars were pushed by hand or hauled by horses.

Ransome Steel Forms. Ransome steel forms were used. These are built much as the Blaw forms, with three pin joints, but with 7½ feet square-end panels requiring the use of wooden fillers to pass curves. Plates of these forms were ¼ inch stiffened by 5 inch I-beams bent to the curve of aqueduct. The interior forms were moved by a wooden carriage operated by a hand windlass which rotated side leaves, collapsing or raising the forms, the windlass being connected to chains geared to the axle. Although the carriage gave considerable trouble at the start it worked fairly well later on, but apparently not as well as the positively operated carriage with screw-jacks commonly used elsewhere.

Hand Labor Inadequate. Installation of Steam Shovel. The work of the first season made it clear that hand labor alone could not be relied upon to excavate the trench in advance of the invert, except at a ruinous cost or at a very slow rate. A small Vulcan shovel was obtained for the trench and operated during the last season. This shovel excavated and loaded into cars which were run back and dumped over the aqueduct. Concrete brought from the mixer over a narrow-gauge track was placed by the locomotive crane which dumped the Cockburn automatic bucket. An average rate of 15 feet per day was regularly made with a very economical organization, about 90 men being employed for one 8-hour shift. All excavation was in hardpan with no rock except boulders.

Work Accomplished during 1910. On Section 1 during 1910 a determined effort was made to reach Tongore Creek, which would enable the upper mixing plant to be dispensed with. Night shifts were put on and 75-foot sections of arch attempted. Nevertheless, at the end of the season there remained 3176 feet of aqueduct trench incomplete, the shovel having been retarded by a heavy rock cut and even more by a few feet of hard bluestone overlaid by wet ground. Serious inconvenience was also caused in wet ground by attempting to build the culverts in the rear instead of ahead of the shovel. This prevented free drainage, which was otherwise secured by laying wooden box drains below the invert and leading them to holes in sides of completed culverts. It was found that when a few feet of hard rock was overlaid by earth much better work could be done by stripping the rock with steam shovel, backing the shovel to the completed trench, setting up drills and blasting in advance of the shovel, which removed the rock to subgrade, loading into dump cars which ran to crusher or dump.

Preparations during Winter of 1910–11. During the winter of 1910–11 two steam shovels were kept busy on Section 2 excavating several thousand feet of rock trench to subgrade. The rock of the first shovel was either wasted or used to make embankments; that from the second shovel on the deep Atwood Cliff was crushed as previously described. Where necessary the downhill side between Peak tunnel and Atwood was built out by material from the shovel to carry a double narrow-gauge track, the track rock-ballasted and put in first class shape for the next season's work.

Rearrangement of Hains Mixer Plant. The Hains mixer plant at the crusher was moved southward 1½ miles to a more convenient side-hill site. Stone and sand bins were constructed to feed into a bucket elevator. It was found during the previous year that delays ensued because only one bucket elevator was installed, making it necessary to empty the stone bin before raising sand or vice versa. This deficiency was remedied by establishing a stock pile of sand within reach of a derrick, operating a grab bucket with long enough boom to reach the sand bin. Sand, during 1911, was hauled from a pit near the new branch line laid to High Falls and brought in at night in sufficient quantities to be stored at the mixer for the next day's use. The previous year the lack of sufficient sand of good quality was greatly felt, although a long siding was laid to a sand pit at Atwood.

Opening of New Quarry. A new quarry was developed uphill from the aqueduct and an independent track laid to it from the crusher. This quarry together with the s ock pi furn hed sufficient stone to carry on the work at a high rate. During the previous year it was difficult to keep at hand a sufficient supply of crushed stone. The quarry adjacent to crusher being exhausted, the contractor was forced to gather up stone walls at great expense. The new quarry developed a fine face of good bluestone, which after being drilled and shot was loaded into side dump cars by a 60-ton steam shovel. The cars were hauled to the McCully No. 8 crusher. The Ingersoll-Rand drills used were operated by steam. The quarry was called upon to supply about 700 yards of broken stone per day during the summer of 1911, but was not quite able to keep this up, so that the stock pile accumulated during the winter was drawn upon and used up just as the demand lessened.

Efficiency of New Mixer Plant. The new mixer plant at Station 305 proved to be very efficient, largely through the convenient layout of tracks leading to and from it, and to the abundance of concrete material supplied. This layout is shown on Pl. 73. Cement was shifted at High Falls to the narrow-gauge cement cars, hauled by dinkies to a shed at the mixer, and elevat d to the mixer platform by a belt conveyor, most of the cement being directly fed from the cars to a chute supplying the elevator.

Aqueduct on Longitudinal Walls. The shovel after passing Atwood cliff working toward Peak tunnel was able to keep ahead of invert laying without trouble. At the south end of Atwood cliff a large culvert was built at Davis gully. It was originally intended to build the aqueduct on embankment, but this was thought objectionable owing to the difficulty of properly rolling the layers in such a rough place. At another similar situation an embankment was puddled by casting glacial drift, mostly clay, into water dammed up so as to be only a few inches deep. This made an impervious embankment, but unfortunately was found to be still soft and

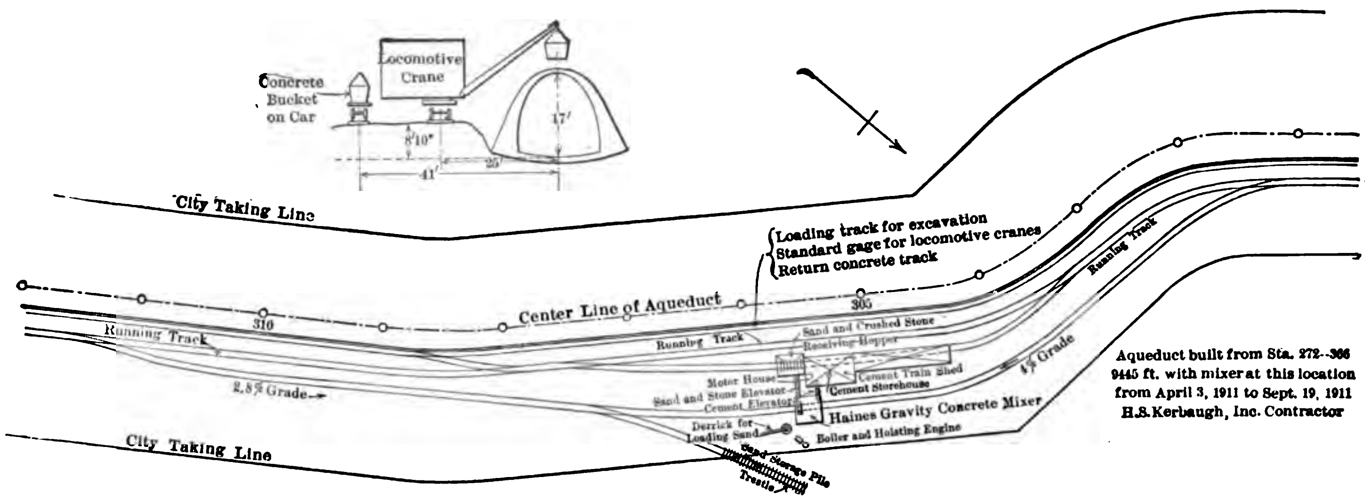


PLATE 73.—Contract 11. Diagrammatic Layout of Haines Concrete Mixing Plant on Section 2. This was the most successful plant on Contract 11. 9445 feet of aqueduct were built in one season with concrete from the plant. Shows method of placing concrete with locomotive crane.

quaking the following year. In this instance, three walls and, in the Davis gully case, two longitudinal walls, were carried down to hard ground, and filled between with good material which was shaped up as a form for longitudinal arches for the invert springing between them and deposited in the usual manner in 15-foot alternate blocks. Upon the invert arches the main aqueduct was built, there then being no fear of settlement. In this manner three of the four embankments were eliminated. The only considerable foundation embankment built on Contract 11 was that at Station 274 (Hendricks Killitje) which was carefully built to a maximum height of about 16 feet (length 900 feet) with material carefully rolled in 3-inch layers. Although very carefully tested no settlement nor cracking of masonry was detected, showing that by careful work embankments can be safely built upon, although they are always a source of anxiety.

Record Progress during 1911. During the season of 1911 only one shift was worked on concreting and excavation, the only night work being the hauling of sand to the mixer and the moving of outside forms. Nevertheless, far greater progress was made than in 1910, when night shifts were in vogue. This was made possible by having a long stretch of excavation completed, a better sand pit, better quarry and trackage, and last, but not least, a better organization. This was accomplished by so systematizing the work that it repeated itself every day. On account of the change of method of laying invert, doing away with key blocks and substituting steel plates, the invert could be laid much faster than in previous seasons, seven blocks, 105 feet, being commonly laid in one shift, while at the same time 60 feet of arch were placed. The dinky train hauled from the mixer six bottom-dump Steubner buckets with eight bag batches (1.5 cubic yards). These were raised over the arch forms by two locomotive cranes, Browning and Bay City, and dumped by men on the forms, rammed and leveled by others between the inside and outside forms, very wet concrete being used. A 60-foot section of about 240 yards was usually placed in about five hours. The invert concrete was deposited in a similar fashion by a locomotive crane. The invert, gaining 15 to 45 feet per day on the arch, soon nearly reached its limit at the Peak tunnel. After the forms on Section 1 were freed, they were set up so that two sections of arch could be concreted in one day. On Section 2 the best day's work was two sections of arch (a 60-foot and 45-foot section, 105 feet total) and 45 feet of invert, totaling 470 cubic yards of concrete, which was hauled an average distance of over $\frac{3}{4}$ mile from the Hains mixing plant. During one week the plant built 690 feet of arch and 180 feet of invert (about 3000 cubic yards). Between May 20th and Aug. 29th inclusive, 6378 feet of arch and 6925 feet of invert were concreted, the best season's work of any cut-and-cover plant on the Catskill Aqueduct.

Completion of Section 1. On Section 1 the remaining 3000 feet south of Tongore Creek was completed without particular difficulty in the season of 1911. After waiting until the bottom had dried out as much as could be expected, the long boom shovel was started up, the cut being carefully drained by box drains laid to the completed culverts or trenches previously dug for culverts. The Hains mixing plant was started and a uniform progress of 45 feet per day at first and later 60 feet per day was made until Section 1 was completed, the excavation being sent back over the uphill track and dumped over completed concrete arch to form embankment. The forms were then sent back to Section 2, and the shovel placed in a borrow pit to finish excavation for embankment.

Summary of Work on Contract 11. The construction of Contract 11 is here given in considerable detail, because it passed through very interesting stages and much experimental work was done before an economical method was developed. To summarize: First, to save costly fuel transportation, all machinery—compressors, etc.—as far as practicable, were operated by electricity, a special transmission line being built along the aqueduct line. Second, compressed air was used to a large extent to furnish power for drilling the Peak tunnel; to operate miscellaneous machinery, such as derricks, pumps, etc.; to operate steam shovels and to drill the rock in open cut along several miles of aqueduct trench. Third, traction engines being found inadequate, a narrow-gauge connection to the Ontario & Western Railroad was built. Had the connection been made the first season much time and money would have been saved, and still more if the connection had been of standard gauge with standard-gauge equipment throughout.

Efficiency of Steam Shovels. For excavation, the steam shovel, Model 60, particularly when equipped with a long boom, was found to be the ideal tool and fully able to keep ahead of concreting in earth cuts, though it required a long start and winter work for the rock cuts, necessitating the spoiling of excavated material to be made good later from borrow pits.

Blaw Forms. For concreting, the steel forms as later made by the Blaw Company were satisfactory and gave good results when supplemented by pipe braces. The electric carriage for moving

PLATE 74.—Contract 11. Cut-and-cover Arch. This section was cast between steel forms with steel plates in expansion joints at 60-foot intervals. Steel plates $6'' \times \frac{3}{8}''$ were placed in both invert and arch joints to act as water stops.

PLATE 75.—Contract 11. Cut-and-cover Aqueduct on Curve. Arch cast with aid of steel forms built wedge-shaped in 5-foot lengths to 200 feet radius. Section 17 feet high by 17 feet 6 inches wide.

inside forms was entirely satsifactory but somewhat expensive in first cost.

Efficiency of Locomotive Cranes. The locomotive crane was found to be an invaluable tool for moving outside forms, placing concrete and doing miscellaneous work. At first a small second-hand Browning hoist was installed and later two double-truck Bay City, and two double-truck Browning hoists. The double-truck hoist was found to be the most efficient. It may be said that an entirely satsifactory and probably the best aqueduct-building plant can be built around the locomotive crane, the problem being to excavate ahead of it, furnish it a track to run upon, and keep it supplied with concrete, and let the crane do the rest. It can excavate with the aid of drag-line scrapers and orange-peel or clam-shell buckets, place concrete, move outside forms, etc., but the best adjunct to it is a long-boom steam shovel and a good stationary mixing plant, dinkies, cars, etc.

Applications of Cut-and-cover Methods to other Work. The method best adapted to aqueduct construction as applied to this and other cut-and-cover contracts is also of wide application, as demonstrated by the very successful application of practically the same methods to a section of subway constructed on Fourth Avenue in Brooklyn. The pipes and sewers in this street, a wide thoroughfare, were first laid to one side and the street provided with plank roadways on each side supported by piles. The bulk of the excavation was then removed by a steam shovel, which loaded cars hauled in trains which were dumped in scows at a convenient point of a neighboring canal.

A stationary mixing plant was constructed below ground, the bins being filled by dumping from the street above. Bottom-dumping concrete buckets were loaded in the cut below directly from a rotary mixer, and hauled in trains to a locomotive crane operating in the cut, which dumped the cars over steel forms. The forms were furnished by the Blaw Company, and operated in carriages somewhat as the cut-and-cover aqueduct forms. The section was of reinforced concrete, and all four tracks were cast at once, in lengths of about 30 feet. Very rapid progress was made and the work was economically done by the method outlined above.

A stationary mixing plant and locomotive crane for general use and concreting were very successfully used in a similar manner at a long drydock in the Brooklyn Navy Yard, by Holbrook, Cabot & Rollins.

In placing the foundation of the Adams Express buildings the work was laid out so that two locomotive cranes served a large number of compressed-air caissons doing a great deal of miscellaneous work, removing excavation, placing concrete, etc., and dispensing with all the usual derricks at a considerable saving.

Efficiency of Hains Mixer. The Hains mixing plant performed the service it was called upon to do and was able to mix good concrete, but some difficulty was experienced when rather dry concrete was attempted. It requires greater skill and experience for operation than ordinary rotary mixers, but when a gang is thoroughly broken in to the work, it excels any mixer in speed and capacity. It is probable that its first cost and operation are more expensive than the ordinary rotary mixer (such as Smith or Ransome) where used to furnish the amount of concrete ordinarily used on aqueduct work. The Hains mixer requires rather heavy timbering, owing to the height necessary to obtain the gravity mix through the conical hoppers; also to get the best speed requires separate sand, stone and cement elevators. A stationary rotary mixer plant with overhead bins is much lower, requires much less framing and can be supplied with concrete material by elevators or derricks and is, therefore, more readily taken down and transported from place to place. The Hains mixer is said to work better with gravel than broken stone.

The advantage of the Hains mixer is that it mixes easily from 50 to 75 yards of concrete per hour, and is economical for anything over 400 yards per day of eight hours. It required about 22 men for its operation on Contract 11, where it was necessary to mix to its capacity, requiring a large amount of rolling stock, etc.

Repair Plant and Machine Shop. From the beginning of the work a large and well-equipped machine and carpenter shop was operated at Atwood, which was later connected with the contractor's tracks. This shop proved to be a good investment and did much to keep the work going smoothly, saving breakdowns, etc., and accounts in a large measure for the fine record of uninterrupted work on this contract. It was electrically operated and supplied with compressed air from the tunnel plant which was used for a large steam hammer and for other purposes.

Rock Trenches. It was found very difficult to excavate the surface rock to the lines of the minimum rock section (21 feet wide, 6 on 1 slope). Although carefully drilled to within the line, the powder worked along numerous seams and heads, widening the trench in an irregular way. In some case after the shovel passed, the sides had to be pulled down to prevent falls. Later this was prevented by allowing the shovel in the final cut to tear down all loose rock.

Payment Lines in Rock. Nothing in the contract prevents the board from widening payment lines, so that the contractors were partly compensated for the wide breakage. However, even so, a considerable saving to the city was effected over the maximum section in rocks which otherwise would be paid for if no attempt to excavate economically were made. The excavation of the rock trenches was carefully watched, as the depositing of concrete invert and sides against shattered rock is liable to cause leakage when the aqueduct is full. Nothing short of channeling, which is entirely too slow and expensive, and not contemplated by the contract, can be expected to give good rock sides. It is probable that if the work were to be done over again a modified rock section would be advisable, somewhat narrower at the base than the loose earth section, but with the same waterway. The trench could then be blown out with no concern as to the sides, and the aqueduct constructed between inside and outside forms as in loose earth. This is also true of the firm earth section (Type B) which was not practicable to nearly the extent first thought. The invert in rock was usually deposited on rock spalls or débris. To prevent leakage an occasional block was cleaned out to firm rock and concreted. This was done at each side of culverts to prevent leakage into them.

Testing of Aqueduct in Sections. At the suggestion of one of the department engineers (Mr. Ridgway) a provision was inserted in Contract 11, and all subsequent cut-and-cover contracts, requiring the testing, under regular items, of sections of aqueduct during construction. Stretches of from 200 to 400 feet were bulkheaded off at specified points and filled with water and the leakage observed by measurements of the water surface. Careful examination was also made of leaking joints, etc. In some cases, slight repairs were made, such as caulking or grouting leaking joints and new tests then made. This gave invaluable information and kept the contractor and engineers on their mettle, resulting in improvements in construction, particularly the discarding of the concrete tongue-and-groove expansion joint and key blocks and the substitution of the steel plate joint.

Grouting of Joints of Cut-and-cover Aqueduct. The hydrostatic tests made on various contracts showed that both the concrete key and steel plate expansion joints were liable to leakage, due

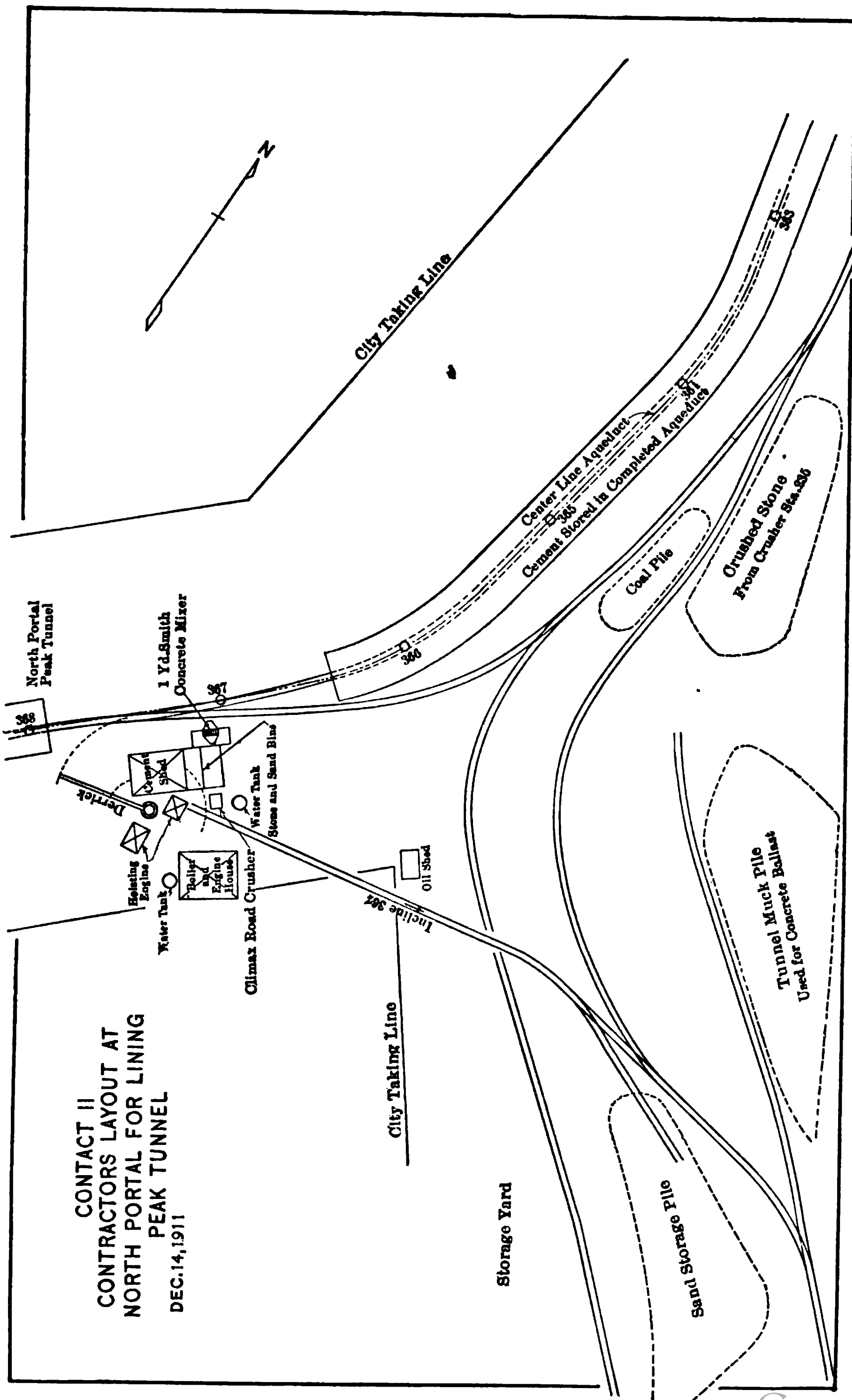


Plate 76.—Contract 11. Diagrammatic Layout of Concrete Plant at North Portal of Peak Tunnel.

probably to breakage of the keys and tearing of the concrete adjacent to the plates. After repeated trials of different methods of repairing broken joints, such as caulking with oakum, etc., it was found that grouting was most practicable. Tests made on sections before and after grouting indicated that about 80 per cent of the leakage could be cut off by this means. Small parties were organized during the winter season of 1911–12, when the joints were widest. With a very simple equipment of grout box and tin funnel, or coffee can, after the joints were superficially caulked with oakum or mortar, they were poured full from the top with a few quarts of neat cement grout. This grout also tends to run into and close the invert joints. All the work was done from the inside. In this manner, at a very slight expenditure, the aqueduct was made tight.

Concreting of Peak Tunnel. Two small crushing and concreting plants were placed at each portal of the Peak tunnel during the fall of 1909, with the expectation that the tunnel would be concreted the following winter. This was not done, owing to delay in delivery of the forms and to trimming. As the rock in the tunnel weathered remarkably well, the delay did no harm and saved the concrete from bad smoking up by the dinkies. The south portal plant was used as before described for concreting invert ahead of large traveling plant in cut-and-cover. During the winter of 1910–11, the tunnel was finally trimmed amd the footing course concreted, using the plant at the south end. In the fall of 1911 three sets of Blaw steel forms were installed in the tunnel and concreted at the rate of about 40 feet per day, the bulk of concrete being placed in one shift, the keying up extending into another. A set of 40 feet of forms were moved and made ready each day for concreting. A 20-ton shovel filled cars with tunnel muck suitable for crushing. The cars were hauled up to the foot of the incline and then by cable to the crusher and dumped by hand. The crushed rock passed into a bin directly over a Smith mixer which discharged into Koppel cars hauled into the tunnel by mules to the foot of an incline and hauled up the incline by cable; the cars were dumped upon the platform, whence the concrete was shoveled into the side forms or over the arch, taking from twelve to fourteen hours for a 40-foot section.

Progress in Concreting Peak Tunnel. Between November 8, 1911, and February 18, 1912, elapsed time 103 days, 3470 feet of tunnel lining were placed, an average of 33.7 feet per day. A section was concreted each day for forty-two working days. The contractor believes he could as readil have concreted 45 feet per day with the same plant and force if he had had sufficient forms.

PLATE 77.—Peak Tunnel Fully Excavated and Ready for Concrete Lining. Footing Courses are in Place. Center Track for Hauling Material, to Upper Portion of Contract 11. Tunnel is 3450 feet long on tangent.

The invert was concreted by the method firs u ed for the south half of Bonticou tunnel. One half o he invert (about 7 feet) was defined by a longitudinal st:ip and transverse strip every 15 feet to define the grade and to guide the surface screeding. Concrete was delivered over a track placed on the other half and dumped directly into place. Great speed was made by this method, the whole 3360 feet of 14-foot invert 5 inches thick being placed in sixteen days, as much as 915 feet of half invert being made in one day.

It is believed that the progress made in concreting the Peak tunnel is about the best of any grade tunnel on the aqueduct. It was due to the lessons learned from previous tunnels and to the admirable organization of the work, and also to the fact that all the trimming had been completed after laying footing courses previous to the placing of arch forms.

Later in lining Garrison tunnel, Contract 2, in 1913, much greater progress was made from a single concrete plant at a central shaft.

CHAPTER VIII

RONDOUT PRESSURE TUNNEL AND NORTH HALF BONTICOU GRADE TUNNEL

CONTRACT 12

General Description of Contract 12. This contract was let in June, 1908, to the T. A. Gillespie Company, and comprised a short stretch of cut-and-cover adjacent to Contract 11, $4\frac{1}{2}$ miles of pressure tunnel under Rondout Creek near High Falls, and 3340 feet of Bonticou grade tunnel. This contract totaled $6,290,803, being the largest aqueduct contract and the one on which, up to the present time, the most difficult work was accomplished. The tunnel was constructed from eight shafts, varying in depth from 370 to 708 feet. The shafts and tunnel penetrated material varying in hardness from shale to millstone grit. Some strata were found to be dry, others porous and water bearing, besides containing quantities of irritating sulphur gas. Very numerous borings, made previous to the letting of the contract, and elaborate porosity and pumping tests made on these same holes, gave pretty definite information as to the difficulties which would be encountered. It was aimed to have the aqueduct completed between Ashokan Reservoir and Croton Lake by the time a portion of the reservoir would be ready to impound water, and as the Rondout siphon was considered the most difficult piece of work, the contract called for its completion in fifty-four months.

Preliminary Investigations. During the advertising of the contract, all information obtained by borings and pumping tests was shown to intending bidders, so that the work could be bid on with a full realization of the difficulties to be encountered. On their face the prices obtained by the contractor, although he was the lowest bidder, may seem high, but taking into consideration that this was the first siphon to be constructed and the known difficulties to be encountered, they are probably fair. The following description will show that the contractor spared no expense and pains to make this work successful, supplying the work with the best machinery

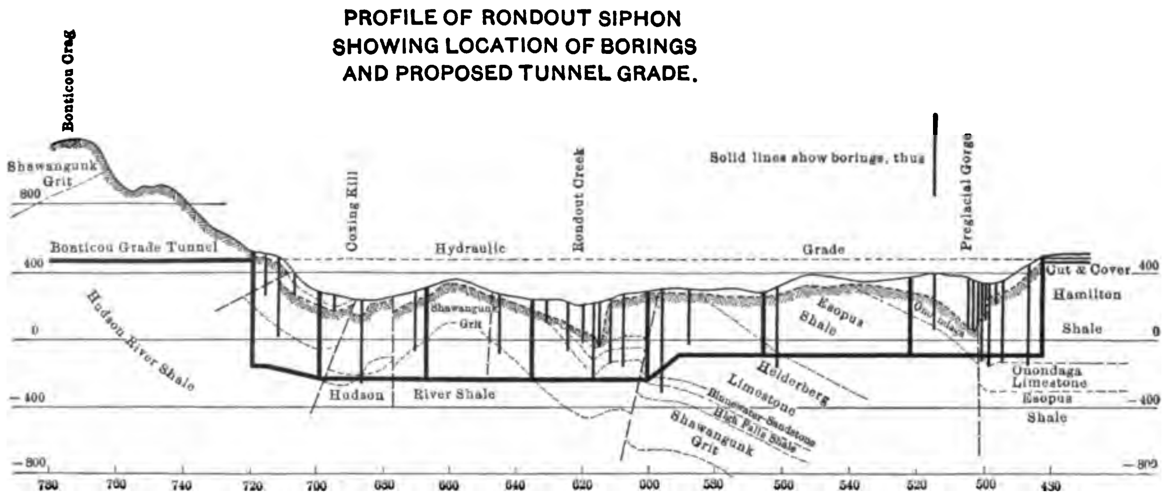


PLATE 78.—Contract 12. Profile of Rondout Siphon, Showing Location of Borings and the Strata Penetrated by Tunnel. Tunnel was built on grade shown. Lower level −250 feet, upper −100, with 15 per cent connecting slope. Heaviest vertical lines show positions of the eight shafts. Shaft 4 was sunk at Station 607+50 instead of Station 600, as shown. Trans. Am. Soc. C. E., LXXIII, 1911.

and plant which could be obtained, and manning it with experienced and capable superintendents and skilled workmen.

Unusual Pumping Provisions. Contract 12 contains special provisions under Items 10, 14 and 15 which it is of interest to note here. As the Rondout siphon was the first pressure tunnel and the indications from borings and geological investigations were that

PLATE 79.—Spouting Diamond-drill Hole over Tunnel. This hole ceased to flow when tunnel was driven below. Flow renewed when lining was grouted.

quantities of water were likely to be met with in certain formations, special provisions were inserted with the object of eliminating as far as practicable some of the risks involved in this kind of work, or, to put it differently, the City undertook to help the contractor finance the work by paying separately for the pumping plant under Item 14, and also for the actual pumpage of water from the shafts, under Item 15. In addition, bidders were given an opportunity to bid separately under Item 10 for excavation of tunnel in Shawangunk grit, Binnewater sandstone, and High Falls shale, these being the formations where it was expected water would be encountered in the largest quantities.

Pumping Plant. The pumping plant was bid upon in a lump sum of $120,000, but was paid for in installments corresponding to equipment furnished. The pumps were to be furnished in anticipation of the need when water would be encountered. The equipment included the sinking pumps and the stationary pumps for the tunnels. The ordinary sinking pumps were to be eight of 150 gallons per minute capacity and two of 300 gallons capacity. In addition, horizontal station pumps were to be furnished for chambers in the shafts where required. For this equipment Cameron pumps were used exclusively, operated by air from the central power plant. An emergency outfit to control a flow of 1800 gallons per minute at any one point was also to be furnished to cope with the maximum flow expected. This equipment was required, as water was encountered in great volumes in Shaft 4, as hereafter described. It was found almost impossible to put pumps for this maximum flow into a shaft while sinking, so that inflow into the shaft was kept below this amount by grouting, and the number of pumps at the bottom of the shaft decreased by intercepting a considerable volume of water pumped by horizontal station pumps from a chamber. Later, when the large flow was encountered in the tunnel just north of Shaft 4, in addition to the large equipment of horizontal air-operated reciprocating pumps, three electrically operated Worthington pumps were also installed.

Item 14 undoubtedly assisted the city in obtaining a plant adequate to cope with the unusual conditions at and near Shaft 4. Without it, there might have been considerable hesitation on the part of the contractor to furnish the expensive equipment which proved to be necessary. The contract provided that the power plant be of sufficient capacity to operate the pumps in addition to the other necessary equipment. The contractor installed a much larger power plant than would otherwise have been necessary. This foresight justified itself.

Payment for Pumpage. Under Item 15, the contractor was paid 30 cents per million foot-gallons pumped, the lift being figured from the point of inflow into the shaft or tunnel to the top of the shaft. This price was rather low and did not pay the cost of pumping where small quantities of water were handled. It was only after the electrical pumps were installed at Shaft 4 and a steady pumpage of 1200 to 2100 gallons of water per minute was maintained, that the price paid covered the cost. This worked out as intended, as this item was inserted for the purpose of tiding the contractor over unusual difficulties. Although the original estimated pumpage was 600,000 million foot-gallons, this quantity was considerably exceeded. All the subsequent pressure tunnel contracts contained items similar to Item 15 of this contract, but none except contract 90 for the Hudson siphon contains an item similar to 14, Contract 90 being the only other contract where any considerable difficulty in handling water was anticipated. It may be stated that to date (March, 1912), the water encountered in the other contracts was small, and very insignificant compared to that of this contract.

Contract Prices. The detailed tabulation of the successful bid is here given. On the basis of the contract prices and quantities the linear foot costs have been estimated as follows: 490 feet of cut-and-cover aqueduct at $80 per foot; 3340 feet of grade tunnel at $107.48 per foot; 23,715 feet of pressure tunnel at $248.46 per foot (includes shafts, chambers, etc.). Subdivisions of the above are as follows:

Construction Shaft.		Waterway Shaft.		Drainage Shaft.		Tunnel.
Earth.	Rock.	Earth.	Rock.	Earth.	Rock.	
$276.59	$380.48	$350.32	$285.02	$400.76	$335.39	$180.42

Specification Contract 12. To give a better understanding of the specifications of a typical tunnel contract the following is quoted from the provisions of Contract 12.

BOARD OF WATER SUPPLY OF THE CITY OF NEW YORK

Contract 12, Rondout Pressure Tunnel and One-Half of Bonticou Grade Tunnel, Catskill Aqueduct

(Canvass of Bids opened June 2, 1908)

The T. A. Gillespie Company, 90 West Street, New York City.

Item.	Description.	Unit.	Quantity.	Price.	Amount.
1	Construction shaft, in earth	Linear foot	150	$250.00	$37,500.00
2	" " in Shaw. grit, Binnewater sandstone and H.F.shale	"	700	350.00	245,000.00
3	" " in all kinds of rock not included in Item 2	"	1,525	350.00	533,750.00
4	Refilling construction shafts	"	150	12.00	1,800.00
5	Waterway and drainage shaft in earth	"	160	250.00	40,000.00
6	Rock excavation in waterway and dr. shaft in S. grit, B. sand, and H. F. shale	Cubic yard	4,300	15.00	64,500.00
7	Rock excavation in waterway and dr. shaft in rock not incl. in Item 6	"	14,000	15.00	210,000.00
8	Timbering in waterway and drainage shafts	M. ft. B.M.	590	70.00	41,300.00
9	Maintenance and removal of shaft timbering	"	730	30.00	21,900.00
10	Excavation of pressure tunnel in S. grit, B. sandstone and H. F. shale	Cubic yard	41,000	10.00	410,000.00
11	" " " rock not incl. in Item 10	"	223,000	9.00	2,007,000.00
12	Furnishing structural steel roof support	Pound	1,175,000	.04½	52,875.00
13	Erecting structural steel roof support	"	1,175,000	.04½	52,875.00
14	Construction pumping plant	Lump sum	....	....	120,000.00
15	Pumping from shafts and pressure tunnel during construction	Mil. ft.-gals.	600,000	.30	180,000.00
16	Drainage channels for shafts and pressure tunnel	Lin.ft. sh. tun. and dr.	27,790	2.50	69,475.00
17	Forms for lining of waterway shafts and outer lining of drainage shafts	Lin. ft. of shaft	1,750	8.00	14,000.00
18	" inner lining of drainage shaft	"	485	8.00	3,880.00
19	" lining pressure tunnel and drainage drift	Lin.ft. tun.&dr.	23,690	4.00	94,760.00
20	Concrete masonry in shafts	Cubic yard	11,500	10.00	115,000.00
21	" " pressure tunnel and drainage drift	"	110,000	8.00	880,000.00

22	Drainage interlining in drainage shaft	Square foot	23,500	.30	7,050.00
23	Furnishing and erecting steel castings and erect spec. valves in dr. sh. and dr.	Pound	7,500	.10	750.00
24	Bronze access door and frame	"	8,500	.80	6,800.00
25	Structural steel interlining in drainage drift and pressure tunnel	"	60,000	.07	4,200.00
26	Cutting channels for water-stops	Square foot	450	2.00	900.00
27	Lead-lined 16-inch cast-iron flanged pipe and specials	Linear foot	550	30.00	16,500.00
28	Excavation of grade tunnel	Cubic yard	37,000	6.00	222,000.00
29	Permanent timbering in grade tunnel	M. ft. B. M.	80	70.00	5,600.00
30	Grade tunnel drainage	Lin.ft. of tun.	3,340	1.50	5,010.00
31	Forms for masonry lining in grade tunnel	"	3,340	3.50	11,690.00
32	Concrete masonry in grade tunnel	Cubic yard	9,900	7.00	69,300.00
33	Temporary timbering	M. ft. B. M.	150	70.00	10,500.00
34	Additional trimming in shafts, tunnels, and drift	Square yard	600	8.00	4,800.00
35	Excess concrete masonry in shafts, tunnel, and drift	Cubic yard	6,000	3.00	18,000.00
36	Brick masonry in shafts and tunnels	"	200	15.00	3,000.00
37	Dry packing in tunnels	"	8,500	3.00	25,500.00
38	Drilling 1½-inch or smaller holes in rock or masonry	Linear foot	2,500	.40	1,000.00
39	" 1¾-inch to 2½-inch holes in rock or masonry	"	2,500	.50	1,250.00
40	Steel pipe for grouting, etc.	"	50,000	.40	20,000.00
41	Miscellaneous plant and equipment for grouting	Lump sum	....	....	5,000.00
42	High-pressure air compressors for grouting	Compressor	14	300.00	4,200.00
43	Tank-grouting machines	Machine	14	250.00	3,500.00
44	Grouting pads	Pad	50	100.00	5,000.00
45	Making connections of tank-grouting machines to grout *pipes*	Connection	8,000	2.50	20,000.00
46	Setting grouting pads	Setting	2,500	1.00	2,500.00
47	Sand for grout	Ton	4,000	2.00	8,000.00
48	Mixing and placing grout	Cubic yard	6,000	6.00	36,000.00
49	Hydrostatic tests of pressure tunnel	Test	2	5000.00	10,000.00
50	Earth excavation in open cut	Cubic yard	33,000	1.00	33,000.00
51	Refilling and embanking	"	50,000	.75	37,500.00
52	Excavating top soil	"	16,000	.40	6,400.00
53	Surface dressing of earth	"	14,000	.40	5,600.00

BOARD OF WATER SUPPLY OF THE CITY OF NEW YORK—*Continued*

Item.	Description.	Unit.	Quantity.	Price.	Amount.
54	Timber and lumber	M. ft. B. M.	75	$60.00	$4,500.00
55	Rock excavation in open cut	Cubic yard	2,000	2.50	5,000.00
56	Concrete masonry in open cut	"	5,500	7.00	38,500.00
57	Reinforced concrete not in tunnel	"	350	16.00	5,600.00
58	Steel for reinforcing concrete	Pound	65,000	.05	3,250.00
59	Miscellaneous cast iron, wrought iron, and steel	"	4,200	.08	336.00
60	Portland cement	Barrel	235,000	1.60	376,000.00
61	Sulphate of alumina for waterproofing concrete, mortar or grout	Pound	500,000	.02	10,000.00
62	Cast-iron pipes and special pipe castings	Ton	21	100.00	2,100.00
63	Ten-inch and smaller sluice gates	Gate	5	60.00	300.00
64	Bronze pipe and miscellaneous bronze	Pound	11,000	1.00	11,000.00
65	Twelve-inch and smaller vitrified pipe	Linear foot	1,700	.50	850.00
66	Dry rubble masonry and paving	Cubic yard	600	3.50	2,100.00
67	Surfacing permanent roads	"	2,200	3.50	7,700.00
68	Reinforced concrete ladders	Linear foot	115	3.50	402.50
69	Locker houses	House	7	1000.00	7,000.00
70	Cleaning up	Lump sum			10,000.00
	Totals				6,290,803.50

Time: 54 months. Bond required, $800,000.00. Engineer's estimates, $5,313,684.00.

SPECIFICATIONS

" NOTE. In numbering the sections of the specifications, the decimal system is used, the figure before the decimal point indicating the item number, and the figure after the decimal point the serial number of the section under the particular item. Where several items are grouped together, as Items 1, 2, and 3, the number of the first item of the group is placed before the decimal point, as 1.1, 1.2, 1.3, etc. The general sections have no decimal point.

GENERAL SECTIONS

Location of Work. Section 1. " The portions of the aqueduct included in this contract are in the Esopus division of the Northern Aqueduct department and situated west of the Hudson River in the towns of Marbletown and New Paltz. The work consists of a pressure tunnel in rock about 4.46 miles long under the valley of Rondout Creek; a portion, about 0.63 mile long, of a grade tunnel in rock under Bonticou crag; and at each end of the first tunnel, a few hundred feet of aqueduct in open cut.

General Description of Aqueduct. Section 3. " The aqueduct will be in its several parts of substantially the sections shown upon the drawings. The pressure tunnel and the waterway shafts will be circular, 14 feet 6 inches inside diameter, the aqueduct in open cut at the north end of the contract 17 feet high by 17 feet 6 inches wide inside, and the grade tunnel and that portion of the aqueduct in open cut between the two tunnels, 17 feet high by 13 feet 4 inches wide inside. Portland cement concrete masonry will be used for lining the tunnels, and the waterway and drainage shafts, and for the construction of the aqueduct in open cut and many of the accessory structures. Certain of the shafts are to be refilled in part, and the aqueduct in open cut covered with an embankment of earth or rock. Spoil-banks are to be shaped to agreeable contours and in some places covered with soil.

Appurtenances of the Aqueduct. Section 4. " At each of the end shafts where the grade aqueduct joins the tunnel which is to flow under pressure, a chamber with screens or guard barriers, stop-plank grooves, drain-pipes, and other appurtenances is to be placed; and at Shaft 5 an access door and drift to the tunnel, and a chamber for a permanent drainage plant are to be installed, with a blow-off pipe and a conduit to lead the water to Rondout Creek. Landscape work is to be done around and in the vicinity of these chambers and roads built to connect them with highways. Spoil at other shafts is to be so deposited as to be as unobjectionable in appearance as practicable.

Orders. Section 11. " Whenever the Contractor is not present on any part of the work where it may be desired to give directions, orders may be given by the Engineer, and shall be received and obeyed by the superintendent or foreman who may have charge of the particular part of the work in reference to which orders are given.

Lines and Grades. Section 12. " All lines and grades will be given by the Engineer, but the Contractor shall provide such materials and give such assistance as may be required, and the marks given shall be carefully preserved. The Contractor shall keep the Engineer informed, a reasonable time in advance, of the times and places at which he intends to do work, in order that lines and grades may be furnished and necessary measurements for record and payment may be made with the minimum of inconvenience to the Engineer or of delay to the Contractor. Whenever the Engineer finds it necessary to carry on his operations on Sundays, legal holidays, or at other times when the work of the Contractor is not in progress, the Contractor shall furnish all necessary service and assistance in shafts and tunnels. No special compensation shall be made for the cost to the Contractor of any of the work or delay occasioned by giving lines and grades, or making other necessary measurements, or by inspection; but such cost shall be considered as included in the prices stipulated for the various items.

Information about Quantities of Materials. Section 16. " To aid the Engineer in determining the quantities of metal work, cement and other materials to be paid for, the Contractor shall, whenever so requested, give him access to the proper invoices, bills of lading, and other papers, or shall provide scales and assistance for weighing, or assistance for measuring, any of the materials.

Planimeter. Section 17. " For the estimating of quantities in which the computation of areas by geometric methods would be comparatively laborious, it is stipulated and agreed that the planimeter shall be considered an instrument of precision adapted to the measurement of such areas.

Contractor's Telephone System. Section 19. " The Contractor shall install and at all times maintain in good working order a telephone system connecting the bottom of each shaft with the shaft head, and connecting each shaft head with the Contractor's central offices and central power house, if any, and with the Section Engineer's offices near Shafts 2 and 7. All telephone instruments above ground, and the arrangements of telephone circuits and switchboards shall be such, and such connections shall be made, as to permit telephone communications from any shaft head to the office of the Division Engineer near High Falls station.

Repair Shops and Duplicate Parts. Section 20. " The Contractor will be required to establish one or more suitable repair-shops, at or near the site of the work, and he shall also have at the site of the work, at all times, duplicates in good condition, of such machines or parts of machines or appliances as are especially likely to wear rapidly, or break, or be lost.

Power. Section 42. " All power machinery and tools within the tunnels and shafts shall be operated by electricity, compressed-air or hydraulic power, except that permission may be granted for the temporary use of steam at the outset of the work, while plants of the required kind are being installed.

Lighting. Section 43. " Tunnels and shafts shall be lighted with electric lights in sufficient number to insure proper work and inspection. Lamps for general illumination along uncompleted portions of the tunnels and completed portions through which materials or men must pass, shall have an illumination equivalent to one 16-candle-power lamp for each 35 feet of tunnel. At headings, at places where forms are being erected, concrete or packing placed, grouting done and at any other points where work is going on or inspection is to be made, adequate special illumination shall be provided.

Lighting of Shafts. " No general illumination of the shafts, except where work is going on, will be required, but the shafts shall be wired throughout, and suitable water-proof outlets to which lamps or flexible conductors can be readily attached, shall be provided at intervals of not more than 50 feet. The wiring circuit for these outlets in any shaft shall be separate from the circuits for furnishing light or power at the pumping-stations and in the tunnel; and there shall be no outlets in the shaft on the latter circuits. Current shall be at all times shut off from the shaft-lighting circuits except when lights in the shaft are in use.

Wiring. Section 44. " All wiring for electric light and power shall be installed and maintained in a first-class manner, and at all points securely fastened in place. Unless otherwise permitted, circuits separate from lighting circuits shall be used for all power purposes. All permanent wiring in shafts shall be installed in waterproof metallic conduits securely fastened to the timbers. Electric light and power wires shall be kept as far as possible from telephone or signal wires, or wires used for firing blasts. In shafts, light and power wires shall not come within 2 feet of wires for firing blasts, and they shall not be placed on the same side of any tunnel with the firing wires.

Open Flames. Section 45. " Unless expressly permitted, no open flame light, nor other open flame, shall be used in any headhouse, nor in any tunnel, nor in any timbered shaft after it shall have reached a depth of 100 feet.

Ventilation. Section 46. " A supply of fresh air sufficient for the safety and efficiency of workmen and engineers shall be provided at all times throughout the length of any tunnel or shaft, especially at the headings, and provisions shall be made for the quick removal of gases generated by blasting or by dust-producing machinery if installed in the tunnel. Ventilating plants shall be so arranged that either the plenum or the exhaust method can be used and changes from one system to the other made at will.

Safety Devices for Shafts. Section 47. " Buckets if used for hoisting materials during the sinking of shafts shall be equipped with cross-heads which run on guides to the bottom of the timbering. Cages shall be used for hoisting men and materials during the construction of the tunnel, and full precautions shall be taken to insure perfect safety. These precautions shall include safety-catches of best design, with bronze or bronze-bushed bearings, landing dogs at all landings, and effective devices for the prevention of over-winding. The efficiency of all safety devices shall be established by satisfactory tests before the cages are put into service, and at least once in three months thereafter. Cages shall be provided with strong protective roofs. The shafts at their tops and all intermediate stations or landings shall be surrounded by tight guard fences or closed with tight hatchway doors. All doors and hatches shall close automatically. Effective and reliable means shall be provided for indicating at all times to the hoisting engineman, the position of buckets or cages. Strong ladders shall be maintained at all times, from the lowest working place at each shaft to the top. Covered landing platforms upon which men can pass or rest, shall be provided at vertical intervals not exceeding 20 feet. In addition to the telephone system, effective and reliable signaling devices shall be maintained at all times to give instant communication from the foot of the shaft and each intermediate station to the engine room.

Types of Pressure Tunnel to be Used. Section 48. " It is now intended to build pressure tunnel of types A, C and E, rather than types B, D and F. If, however, the excavation of shafts has not progressed in accordance with the requirements of Article VI, or if the rock seems to be such as to make it advisable not to leave it long exposed to the air, the Engineer may order the work done in accordance with the last mentioned types, and the Contractor shall then carry on lining of side walls and arch simultaneously with excavation, so as to keep the lining finished to within 500 feet of the heading. The Engineer may also order tunnel that has once been excavated in accordance with types A, C and E to be trimmed out to types B, D and F in order that it may be promptly lined. If the trimming is ordered on account of the desire to protect the rock from decomposition, it shall be paid for under Item 34, Additional Trimming; if it is ordered because the Contractor is delinquent in progress, it shall be paid for under the regular items of tunnel excavation. It is intended usually to construct the pressure tunnel and the lower 100 feet of permanent shafts in accordance with the right half of the cross-sections, that is, 12 inches thick to the 'A line' in shafts, unsupported tunnel and lower part of supported tunnel; and the upper parts of permanent shafts in accordance with the left half of the sections, that is, 10 inches to the 'A line.'

Reference Lines on Shaft and Tunnel Sections. Section 49. "Certain reference lines, designated as the 'A line,' the 'B line' and the 'C line,' are shown on the contract drawings. Wherever they appear on these drawings, or on construction drawings which may be issued from time to time, they shall have the significance described in the following sections.

"A Line." Section 50. "The 'A line' is the line within which no unexcavated material of any kind, no timbering or bracing, and no metallic or other support for the sides, roof or other part of the excavation shall be permitted to remain. The 'A line' is, therefore, the line of minimum thickness of masonry lining wherever such lining is to be built.

"B Line." Section 51. "The 'B line' delimits the excavation to be paid for, whatever the areas of the sections actually excavated. In certain specified cases the 'B line' is also a payment line for masonry and dry packing.

"The 'B line' is fixed arbitrarily 13 inches outside of the 'A line,' except adjacent to permanent support, where it is as nearly as practicable 13 inches outside the support, not counting projecting rivet and bolt heads, and in the invert of the grade tunnel, where it is but 2 inches outside of the 'A line,' except as provided in Section 58. This relative position will not be altered whatever modifications of section may be made, and no pecuniary allowance will be made, except under Item 35, on account of any discrepancy which may develop between the volume within this line and the volume actually excavated. Information is on file in the office of the Engineer and may be seen by bidders, relating to the distance between lines corresponding to the 'A line' herein described and the position of the average line of excavation in a number of well-known tunnels.

"C Line." Section 52. "The 'C line' is the line of effective average thickness of masonry lining. Rock or other foreign materials will be permitted to remain within the 'C line' only under circumstances such that the effective strength of the lining against external pressures, below grouting, considered in lengths not exceeding 4 feet, is not thereby reduced.

"Since the natural breakage of the rock in ordinary methods of tunneling is such that only a very small percentage will remain in close proximity to the 'A line,' the 'C line' in unsupported portions of shafts and tunnels in rock has been placed 5 inches outside of the 'A line.' Whatever the method of tunneling, any edges or flat surfaces of rock remaining within the 'C line' to an extent, or in a manner which would impair the strength of the lining, shall be trimmed away sufficiently to make an effective average thickness at least as great as to the 'C line.'

Non-permanent Materials in Lining. Section 54. "Foreign materials imbedded in the lining of shafts or tunnels, if they are, like wood, non-permanent or more compressible than masonry, shall be placed not only so as not to violate the provisions of Sections 50 and 52, but also so as not to interpose a too continuous cushion between the masonry and the rock. Thus in pressure tunnel no wood lagging or continuous wood posting is permissible, and in grade tunnel continuous lagging is permissible over the top of the arch only.

Section 55. "Definite thicknesses of lining masonry are shown on the drawings of standard types of tunnels and shafts, but these thicknesses are subject to modification, provided no thinner lining shall be ordered in the case of pressure tunnel and shafts than shown on the lighter, or left-hand, half-sections on the drawings, and in the case of the grade tunnel than one inch less than shown on the drawings.

Construction Pumping Plant

Item 14

Work Included. Section 14.1. " Under Item 14 the Contractor shall furnish and erect, renew, replace if damaged or destroyed, change about as the work requires, and remove at the end of the work all the pumping machinery, piping and appurtenances, together with the power-generating plants for operating this machinery, required for removing the water from the pressure tunnel and shafts during construction. He shall also, as a part of Item 14, excavate and refill with masonry, as hereinafter described, any spaces in the rock outside of the 'B line' of excavation of shafts or tunnels, that may be necessary for pump-stations, sumps, etc., provided under this item. Low-lift hand-pumps or other pumps used for local unwatering in connection with preparing the bottom of the tunnel to receive masonry, or for passing water over a section of the invert, are not included in Item 14, but in Item 16 (see Section 16.1, paragraph 7).

General Requirements. Section 14.2. " The pumping-plant shall contain machinery and appurtenances equal to those hereinafter specified in detail, not only for taking care of the water immediately in prospect, but also in reserve for coping promptly with flows up to 1800 gallons per minute, at any one of the several shafts and headings. The equipment for meeting these requirements will be at the Contractor's option, subject to approval. The Contractor shall, within two months after service of notice to begin work, submit a detailed description, with drawings, of the method and apparatus which he proposes to employ, and shall modify this plan promptly if required. The capacities indicated have no known relation to the anticipated quantity of water, but many of the pumps are prescribed as an assurance against possible delay. It is, therefore, of the essence of their value to The City that they be supplied before they can, in the opinion of the Engineer, be possibly needed.

Detailed Requirements. Section 14.3. " Requirements will differ in certain details according as the Contractor elects to pump from the shallower shafts in one lift or in two. A plant to fulfill the requirements outlined in Section 14.2 must contain the following essentials or their equivalent:

Intercepting Water from Earth Shaft. (1) " A pump-station and equipment in each shaft, not waterproofed as specified in Sections 1.4 and 5.8, in which the leakage from above sound rock is more than 10 gallons per minute, so arranged as to pump this groundwater to the surface. The Contractor may elect, in case of small flow, to omit this outfit, but as provided in Section 15.4, the payment for pumping such water will be as if the equipment were installed.

Sinking-pumps. (2) "A sufficient number of sinking-pumps to supply all shafts simultaneously in accordance with their various requirements: eight sinking-pumps of 150 gallons per minute each and two of 300 gallons per minute each, will be considered a reasonable initial provision. All pumps shall have the capacity prescribed when operating against the maximum head required.

Station Pumps. (3) "Station pumps for the bottoms of shafts and for the intermediate stations. Each station shall have more than one pump unless that is a double one. In general, two units each of 150 gallons per minute continuous capacity will suffice, but other units shall be in readiness so as to provide double the capacity in at least three shafts. The small sinking-pumps provided under (2) above, may be used, at the bottoms of the shafts, for a part of this equipment, if desired."

Shaft-sinking Organization. With a realizing sense of the difficulties of shaft sinking Mr. Gillespie very wisely secured the services of two shaft-sinking organizations, the Dravo Contracting Co. and S. J. Harry Co. Both had previously sunk many shafts in the coal regions and they were considered about the best two shaft-sinking organizations in the East. Shafts 1 and 2 were assigned to the Dravo Contracting Co.; shafts 3, 4, 5, and 6 to the S. J. Harry Co. The Contractors elected to sink shafts 7 and 8 directly. Sinking was started early at all the shafts, the work being well under way by July 23. Temporary plants were assembled, pending the construction of permanent power plants. At shafts Nos. 1 and 2, the Dravo Co. installed for each an independent plant, composed of boilers, air compressors, dynamos, steel head frames, etc. These plants were previously used on other shafts, and after completing the work here were again used. Shaft-sinking is not so much a matter of plant as it is of organization and experience. Better progress has been made by simple and comparatively inexpensive plants than in places where much more elaborate plants were installed. It may be of interest to enumerate the machinery used, as follows:

Temporary Shaft Plants. At Shaft No. 1 the temporary plant consisted of a return tubular boiler, bricked in and enclosed in a corrugated-iron building, which also housed a compressor, dynamo, pump, etc. The hoisting engine, with single drum 3 feet in diameter, was installed in a small sheet-iron building 40 feet distant from the shaft. A small portable steel head frame over the shaft completed the plant. Although the engine gave good service till the shaft was put down its full depth of 590 feet it is better not to use friction engines for shaft-sinking, as they are subject to great wear, and when weakened may at any time fail to hold a bucket when raising or lowering men or material. A direct-connected engine without friction drum is much safer and more satisfactory.

At Shaft No. 5 a fair-sized steam plant with compressors was installed. This furnished power for Shafts 4 and 5. Shaft No. 6 was equipped with an independent small plant. At Shaft No. 7 a compressor plant was installed by the main contractor to temporarily furnish power for Shafts 7 and 8, a portion of the main air line being used to transmit the power to No. 8. Although the main power plant was determined upon and constructed in a very short time, considering its size, the temporary shaft-sinking plants installed saved about three months. Shafts Nos. 2 and 3 reached a depth of 200 feet before air was supplied from the central plant; Shaft No. 6 a depth of 150 feet.

Sinking Shaft No. 1 in Earth. Overlying earth at the shafts varied in depth from a few feet to 83 feet; in all but three places the material penetrated was a stiff boulder clay or hardpan. All the construction shafts but one were sunk with the aid of ordinary rectangular timber sets and lagging. At three shafts, circular concrete caissons were sunk to rock; at Shafts Nos. 1 and 5 to serve as permanent shaft lining, and at Shaft No. 2 because it was found impossible to get down with timbering. Shaft No. 1 was timbered to the depth of the siphon chamber, at the bottom of which, at a depth of 23 feet, a steel V-shaped shoe was placed and surmounted by concrete forms. Extending up from the shoe were rods tying it into the first concrete placed. The forms were moved upward until 25 feet of caisson were cast, after which sinking was started, the material being excavated with pick and shovel, loaded in skips, and removed by derrick. As the caisson sank new sections were added. No particular difficulty was met until a depth of 34 feet was reached, when the friction of the sides prevented the caisson descending, although the cutting edge was undermined. This was overcome by loading it with a box containing 250 tons of earth and by lubricating the sides with a moderate amount of water. Finally a depth of 63 feet was reached, as originally planned, but it was found that the ledge was even deeper, the indicated rock being a flat

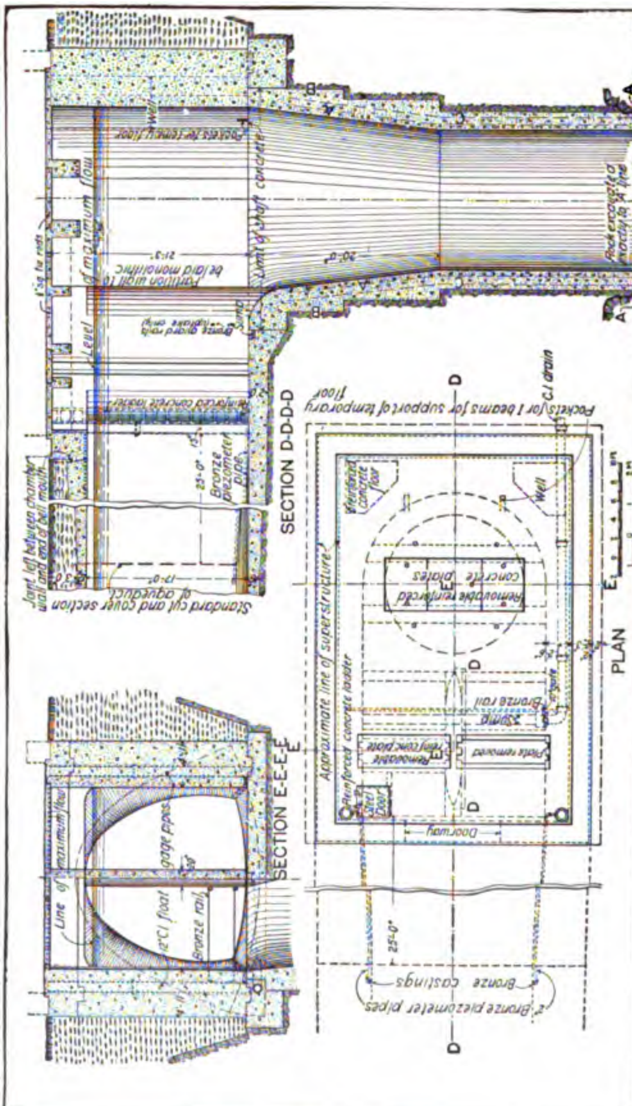


PLATE 80.—Typical Pressure Tunnel Downtake and Uptake Shaft, Showing Junction with Cut-and-Cover Aqueduct.

boulder. The material below the caisson was a remarkably stiff, dry and uniform boulder clay, allowing the earth to be excavated to rock to the required shape. An inside form was placed and concrete deposited between it and the earth. This was brought up to serve as a foundation for the caisson, which is thus practically founded upon rock 20 feet below. Through pipes concreted in the caisson the space back of the caisson was grouted.

Sinking Caisson at Shaft 2. Shaft No. 2 is located near a level plain supposed to be the bed of a glacial lake formed by the damming up of an old stream. The material of the lake bottom is a very fine silt with some clay and when wet may be properly classed as a quicksand. Overlying the rock is quite a bed of large limestone boulders also surrounded by soft material. The boulders may have been carried out into the lake by ice and dropped into its soft bottom. An abortive attempt was made to get down with ordinary wooden sheeting and bracing, but after a few feet had been penetrated this was abandoned.

The method of the drop shaft was next tried. A few feet below the surface a steel shoe was built in place and sections of concrete built on it, forming a cylinder 2 feet thick and 16 feet interior diameter. The caisson was sunk without trouble to a depth of 19 feet, the only difficulty being to excavate quicksand which had to be shoveled from planks. At this depth a little firmer material was encountered and the shoe was undermined. The caisson then suddenly started to drop, and plunged downward $7\frac{1}{2}$ feet in a few seconds, stopping with the top of the concrete just at the level of the soft ground outside. Had it sunk a little more it would have been filled up and probably lost. As the caisson dropped, the material inside the caisson rose, carrying the men working therein with it, but doing no harm. The material in which the caisson dropped was a very fine sand thoroughly saturated with water, but allowing little water to flow through it. Upon being dumped it assumed an almost flat slope, about 1 vertical to 100 horizontal. After a few days, the material gripped the sides of the caisson like mud does a pile, and new sections were built up and sinking resumed. Thereafter the cutting edge was always several feet below the material inside, and it was only exposed when it reached boulders. During the latter part of the sinking the caisson appeared to float around like a huge cork, although weighing hundreds of tons, and at times was several feet out of plumb in different directions. A great deal of material flowed under the cutting edge from without, and large settlements took place, necessitating the moving backwards of the derrick. The sinking was very difficult through the boulders and soft ground. A platform was built on top of the caisson off center and loaded to right it. In addition, compressed air was blown through grout pipes in the concrete shell. This lessened considerably the friction on the side. Finally at a depth of 56 feet the caisson was landed on rock 1½ feet out of plumb with center of gravity shifted 1.1 feet from its original position. By cutting away some of the interior concrete the caisson was made large enough to take two standard cages, and served its purpose admirably, keeping out all water, etc.

Open Caissons vs. Compressed-air Caissons. It will be noted that this caisson was sunk to about 50 feet below ground water without the aid of compressed air and that the difficulties encountered were due to this. With a caisson sunk by compressed air no ground would have been lost and the rock would have been reached without difficulty except that the cost would probably have been higher. Were a drop shaft required to be sunk through similar material where settlement of the surrounding ground was not allowable, compressed air would be required, as in the case of the shafts in lower New York and Brooklyn, where from 30 to 100 feet of wet ground was penetrated.

Caisson at Shaft 5. The third caisson was sunk at Shaft 5, where the surface material was found by borings to be 50 feet in depth. Samples obtained by the borings indicated sand and gravel, and as the rock surface is considerably below the adjacent surface of Rondout Creek it appeared to be a serious matter to reach rock. It was known, however, that wash borings when penetrating hard material tend to wash away the clay, leaving a residuum of sand and gravel. A test pit sunk to a depth of 15 feet showed a compact hardpan composed of clay, sand, gravel and boulders. Nevertheless, it still remained possible that some layers of water-bearing gravel might be encountered.

Sinking of Caisson. After the chamber had been sunk to a depth of 12 feet, sheathed and braced, a heavy steel shoe was riveted up in place and a concrete caisson 16 feet in diameter and 2 feet thick constructed upon it. The requirements at this shaft were very rigid, as it was necessary to sink the shaft nearly plumb on account of the discharge pipe, etc., for the drainage system; also it was necessary that no ground should be lost, as any settlement of the surface would endanger a large drainage chamber to be built at the top of the shaft. Between the horizontal joints of each successive day's work, sufficient steel was to be placed to carry half the weight of the caisson below. When the caisson had sunk to a depth of 20 feet in very dry hardpan the friction became so great that even with the cutting edge entirely undermined it ceased to sink, at this time being 3 inches out of plumb. The outside of the caisson was lubricated with water and rakers were placed inside to right it. It then lowered a little and straightened up so as to be only 1 inch out of plumb. The caisson then stuck very stubbornly, and refused to go even when loaded with 100 tons of stone, the sides lubricated and the interior flooded.

Breaking Apart of Caisson. After trying vainly for a week to get down, several sticks of dynamite were set off in the water without permission. This settled the caisson $3\frac{1}{3}$ feet in a very short time. The concussion must have strained the cylinder, because the following day, when everything was going smoothly, it broke in two, the cutting edge burying itself $2\frac{1}{2}$ feet in the soft clay below, the upper section remaining bound in the boulder clay. The gap between the two parts of the caisson, which had increased to $3\frac{1}{2}$ feet, was concreted and while still soft the upper portion was freed by poking rods along the sides, and it settled onto the lower portion. A few days after the two portions of caisson were reunited, rock was reached at a depth of 50 feet, the caisson being only $1\frac{1}{2}$ inches out of plumb.

It would appear from the experience of sinking these three caissons that the sections should be bound together securely, enough steel being inserted at each joint to carry the weight of the entire caisson below; also that it is difficult to penetrate more than 50 feet of dry material without loading the top very heavily. A good strong V-shaped cutting edge securely tied to the concrete above aids materially in the sinking, as does the guiding of the caisson the first 15 or 20 feet. Similar caissons have been sunk over 100 feet through water-bearing ground, by the use of compressed air and loading with pig iron to overcome a friction of from 600 to 1100 pounds a square foot. This is described under Contract 67, Chap. XX.

Earth Portion of Shaft 8. The sinking of Shaft 8 through 40 feet of drift presented some unusual features. In order to provide room for concreting the siphon chamber, it was started 30′×30′. After penetrating 20 feet of good ground using ordinary timbering and sheeting, soft ground was struck in one corner, causing considerable settlement of the timbering. The situation was saved by a new superintendent, who built a stout horizontal frame on the bottom of the shaft about 2 feet from the sides of the shaft. This frame followed the excavation down and from it small braces were run to support the bottom of the sheeting, which was driven ahead as poling boards in about 6-foot lengths. Using great care and caution, rock was uncovered at 42 feet, and to secure the timbering a portion of the siphon chamber was concreted.

Main Power Plant. It was determined to operate all the machinery as far as possible with compressed air, the contractor not deeming the electric power lines in this vicinity dependable for tunnel purposes. It was anticipated that large quantities of water would be encountered and it would mean flooding of the shafts and tunnels if power were shut off even for a short time. This meant the building of a large power plant to meet the requirements of the 15 headings which might be simultaneously in operation. The master mechanic, Mr. Canniff, with this as a basis, thought it advisable to design the plant to furnish air for the pumps, hoists, crushers, concrete mixers, etc., which were installed from time to time, this being done largely for the purpose of securing the greatest reliability. The additional cost for power over steam and electricity for these purposes was not considered of much moment, inasmuch as the central power plant could furnish air with great economy. An almost ideal location for the power plant was found adjacent to Rondout Creek near the center of the Rondout Siphon. Here a large field was leased and a siding constructed from the O. & W. R. R., this siding ending in a trestle for the delivery of coal. An unlimited supply of fine water for all purposes was obtained from the creek.

Largest Compressor Plant. The power plant for Contract 12 is said to be the largest compressed-air plant constructed for any contractor. Although its life was to be only a few years, it was in all respects constructed as a permanent plant, except for the wooden structure, 80′×160′, housing the machinery. Even this was regretted on account of the fire risk, but to give as good protection as possible, the building was surmounted by a water line which could through numerous openings cover the roof with a flood of water. In addition, numerous fire plugs were connected up inside and outside of the buildings, and the attendants were trained, at a given signal, to instantly spring to appointed places and work the apparatus.

Capacity of Plant. A careful estimate of the probable air consumption was made at the outset as follows:

8 hoisting engines	2600	cu.ft. of free air	per min.
15 headings, 6 drills each (assuming one-half working at a time)	5600	"	"
Miscellaneous use of air	1000	"	"
	9200	"	"

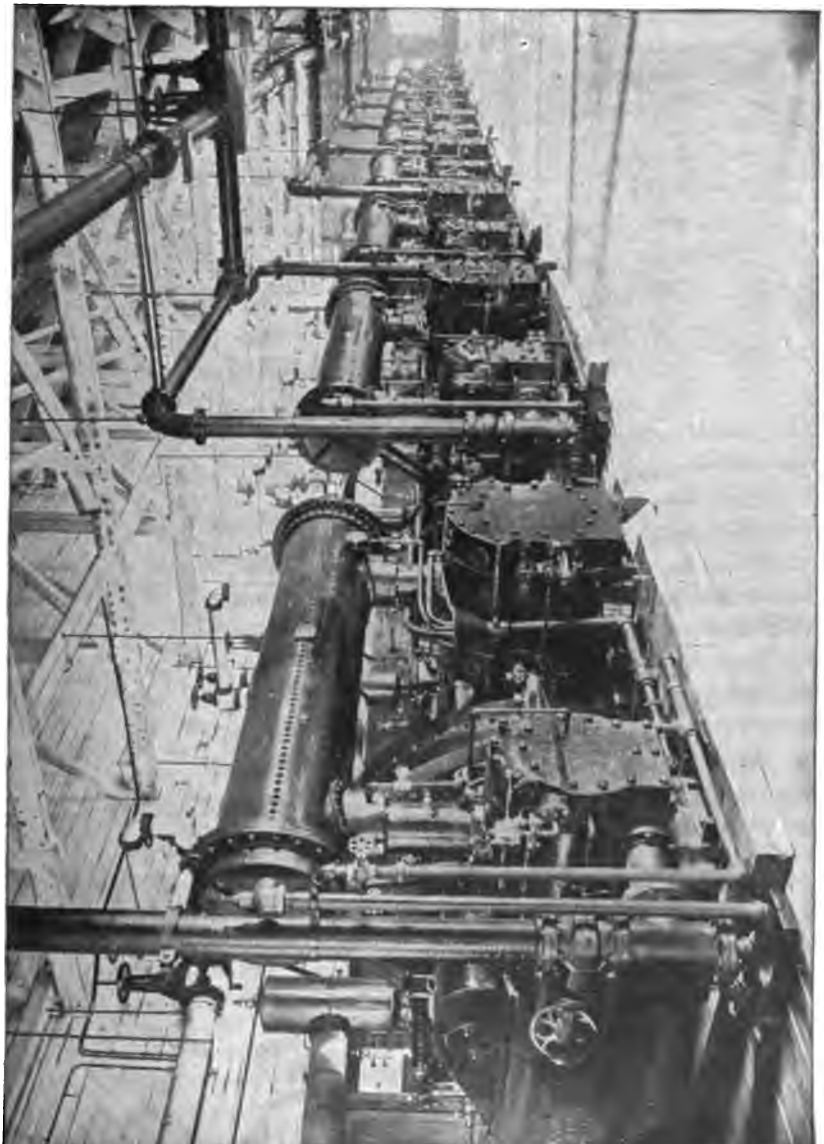


PLATE 81.—Interior View of Power-House for Contract 12. The installation consisted of ten Ingersoll-Rand cross-compound Imperial Type X3 compressors. Total capacity 22,600 cubic feet free air at 110 pounds.

In addition the contract specified that power was to be furnished for a certain minimum requirement of pumps (150 gallons at 6 shafts and 300 gallons at 2 shafts) with an emergency outfit capable of lifting 1800 gallons of water per minute from the bottom of the deepest shaft. These pumps were computed to take 16,820 cubic feet of air, or a total for the entire plant of 26,200 cubic feet of free air per minute compressed to 100 pounds.

Types of Compressors Installed. To supply the above total, ten Ingersoll-Rand compound steam-driven, two-stage air compressors were installed, eight of 421 H.P. and two of 300 H.P. each (see Plate 81). The total capacity of compressors was 22,600 cubic feet of free air compressed to 110 pounds, or with 25 per cent overload, 28,250 cubic feet per minute. The compressors were of the Ingersoll-Rand " Imperial " Type X3 driven by compound condensing engines, equipped with inter-coolers between the low- and high-pressure cylinders and with after-coolers.

Boiler Plant. Coal was brought over a trestle connecting with the Ontario & Western Railroad and dumped directly into bins. Low-priced buckwheat coal obtained from the washeries was used. This was readily handled, but required the use of forced draft. Coal was shoveled by a few firemen from the bins directly into the four Heine water-tube boilers of 380 H.P. and the four Sterling water-tube boilers of 250 H.P. each. By means of the Mason fans which operated automatically by a regulator controlled by the steam pressure, the long grate fires were supplied with air under pressure, very efficiently burning the buckwheat coal and maintaining the steam pressure steadily at 150 pounds.

Auxiliary Plant and Condensers and Generators. The exhaust steam was led to a barometric jet condenser which maintained a high vacuum aided by a 5-inch dry-air vacuum pump. Water for condensation cooling and other purposes was supplied by a 24-inch pipe leading from Rondout Creek to a pit below the river level in which was placed a battery of reciprocating and rotary pumps.

Two General Electric steam turbine generators of 150 K.W. each distributed three-phase 2200 volts current to all the shafts, where it was used to drive the ventilator blowers and for lighting, after being stepped down to 110 volts.

Compressed Air-pipe Lines. The air was distributed at 110 pounds to 12-inch lines, reducing to 10 and 8 inches at the terminal shafts. Down each shaft a 6-inch line was run, branching to 4-inch lines into each heading. The horizontal length of line was 4½ miles. Pressure at the heading was never below 80 to 90 pounds. Each pipe was fitted with a Dresser joint, such as has been successfully used for a long time in distributing natural gas. Plain end pipes with a slight bead were used. They were fitted together in a sleeve between which and two end plates two rubber gaskets were compressed by bolts drawn between the plates. The pipes were fitted together very rapidly on the ground. Each pipe, having an expansion joint, was laid to a very irregular profile and lowered into place in a shallow trench. The Dresser joint pipe makes a very efficient air line, giving much less trouble than the usual screw-joint line.

Performance of Central Plant. Construction on the plant was started July 20, 1908. By Nov. 4 it began to supply air regularly to the various shafts, and to the end of the work there was only one interruption of service, when, at a sharp change in grade, the pipe line pulled apart. The plant was remarkable for the perfect control of the boilers and compressors. The daily disk charts show very small variation in either steam or air pressure. The plant satisfactorily performed the work it was designed for. However, at Shaft 4, where great quantities of water had to be pumped and where it was necessary to install reserve pumps of still greater capacity, a small auxiliary steam plant was constructed to help out the air pumps, and later, connection was made with a power line to operate three six-stage electrical centrifugal pumps.

Sinking Shaft No. 1 in Rock. After 84 feet of earth had been penetrated as described, there remained 509 feet of rock in the shaft. Rock excavation started with progress about one month behind. Nevertheless, the shaft was excavated six months ahead of time, taking only about six months to be put down. The first month only 60 feet was sunk in rock, the superintendent being unfamiliar with circular shafts. A new superintendent increased this to 100 feet per month, then 120, and this by the record month of 138 feet of shaft sunk with 132 feet timbered. There was at that time no shaft on record in this country which had been put down at such a high speed. Later, the same company at Shaft No. 1 on the Moodna siphon excavated 168 feet in Hudson River shale untimbered, and better still at Breakneck shaft made 183 feet in granite, which is undoubtedly the best record in this country. In South Africa there is a record of 213 feet of shaft sunk in one month with Kaffir labor by hand drilling.

Advantage of Circular Shafts. At the time Shaft No. 1 was started very few circular shafts had been sunk in this country, some contractors claiming that they would be difficult and slow to put down. This was apparently borne out by the experience of the first contractors of the Hudson River test shaft, who, however, tried to operate without skilled shaft sinkers. Investigation showed that in England from 3 to 6 feet per day was readily made in circular shafts, including simultaneous brick lining.

Circular and elliptical shafts, concrete lined, were beginning to come in vogue in the coal regions, and as they give the best waterway, and there being no intrinsic reason against circular shafts, they were adopted for all permanent shafts on the Catskill Aqueduct.

Timbering vs. Concreting of Shafts. Considerable thought was given at the time as to whether it was better to timber the shafts, leaving the timbering to be taken out and the shafts concreted after the tunnels were driven, or to sink the shaft in stretches and lining with concrete, thus dispensing with timbering. This was thought too advanced a practice for the first contract, and segmental timbering was specified, and placed as shown in Plate 83. In all the later contracts timbering was dispensed with, it being provided that the shafts were to be sunk in stretches of not more than 100 feet before being lined with permanent concrete. This method has a great advantage of absolutely securing the shaft, and in wet ground cutting off leakage, as whatever water-bearing seams are encountered may be grouted or led away to the ring pumps. Contrary to what was predicted, the shaft sinkers were found to be the most capable of placing the lining, as they are far more skilled in handling themselves and material in shafts than are ordinary concrete men, particularly being able to move and set the forms much quicker.

Organization at Shaft 1. The organization at Shaft No. 1 consisted of an American superintendent and foreman with Slav workmen. These men all had had previous experience in Pennsylvania or West Virginia shafts, the workmen being particularly steady and hardworking. The general method was to have a complete cycle of shaft-sinking operations in one day, and not to attempt to make a greater advance than consistent with such a cycle. By this method a day's advance for sinking was increased from 5 to 6 feet, the monthly progress, including timbering, from 100 to 138 feet.

Drilling and Mucking System. The holes were all drilled in one shaft from tripods, using piston drills. Three circles of holes were used. The first circle of holes, called the cut holes, was 11 feet in diameter and drilled 8 feet deep, sloping inward to blow out a cone; the second circle was 13 feet in diameter with holes 6 feet deep; the third, or trimming holes, sixteen in all, and 6 feet deep were placed on the " C " or effective breakage line required, 17 feet in diameter. The close spacing of the trimming holes is particularly necessary in circular shafts, as they save time in trimming and give the true shape. The five drillers and the five helpers in the shaft took five hours to drill 31 holes, totaling 198 feet, the remaining three hours in hoisting drills, etc., out of the shaft, and in loading and "shooting" the central cone of cut holes. The second shift mucked out the cuts and blasted the second round of relief holes. This shift consisted entirely of muckers, with the exception of one or two drillers, who did the blasting and any odd drilling necessary. The third shift consisted entirely of muckers who removed the material thrown down by the sixteen trimming holes. This last shift had the hardest work.

Record Month at Shaft 1. During March, 1909, the record month, an average of 5 feet 9 inches was made per advance, which corresponds to about 57 yards of rock in the solid, shoveled into buckets in about fourteen hours, each man filling about five buckets of muck in his shift. During the record month 132 feet of shaft was timbered in 8 shifts, which is also the record for shaft timbering. Had no timbering been required, by working Sundays, 170 feet of shaft could have been sunk.

Timbering in Shaft. As the rock was somewhat treacherous, only about 60 feet of rock wall was allowed to be exposed at a time. Hitches or notches in the rock were then cut, and on them heavy round sticks of timber were placed parallel to the segmental timbers above. On these "dead" logs the first set of squared timbers were placed, the next set on posts to space bents 5 feet apart, bolts fastened between, lagging spiked on, and space between rock and lagging thoroughly packed with cordwood. To facilitate the work a firm platform was made in three parts which was raised from one bent to another a section at a time by the winding rope fastened to a ring. This platform formed a firm and secure place for the men to work on. In other shafts much time was lost by the use of insecure platforms of loose plank.

Bonus Paid. The men were encouraged to their best work by being paid a bonus based upon a monthly progress of 90 feet, each 5 feet of timbering counting as 1 foot. During the record month the men received about 40 per cent of their wages in bonus. The contractor was more than compensated by the decreased cost per foot of the shaft.

Rectangular Shafts. Rectangular shafts, such as Shaft 2, were sunk by the method clearly shown on Plate 86. This is a usual method of sinking shafts and with it excellent progress was made in these shafts, varying considerably with the hardness and other qualities of the rock. The best average monthly progress was 89 feet in Shaft 2 in Onondaga limestone. The maximum progress in any rectangular shaft was 102 feet. The average monthly progress made in the following formations are as follows:

Hamilton shale	87 feet
Esopus shale	73 "
Helderberg limestone	55 "
Shawangunk grit	40 "
Hudson River shale	66 "

See also Table, page 273, and at end of book.

Shaft No. 4. Pumping Test at Bore Holes. As anticipated, by far the greatest difficulties were encountered in sinking Shaft No. 4. Diamond-drill holes drilled in this vicinity located at low points yielded strong artesian flows from two porous strata. To further determine the water-bearing character of these rocks, two 4-inch shot-drill holes were put down at alternate locations of this shaft. An attempt was made to pump out these holes with an oil-well rig having a capacity of 90 gallons per minute. At the site of the shaft a discharge of 130 gallons per minute was obtained, exceeding the theoretical capacity of the pump by 50 per cent. This was supposed to be due to the gas in the water, forcing the water through the working barrel of the pump. By means of packers it was arranged to pump the water from below any given level, and it was found that after about a million gallons had been pumped the ground-water level was lowered very little. At the other hole, 750 feet away, the ground water was lowered 53 feet by pumping 2,000,000 gallons. The water pumped from both holes was strongly impregnated with minerals and sulphur gas. These tests gave the impression that the shaft would be very wet, but furnished no definite data other than that the water encountered would be far in excess of 100 gallons per minute. A good idea of these porous rocks was also obtained from an examination of their outcropping in the gorge of Rondout Creek below the falls. It was shown that some of the layers of High Falls shale and Binnewater sandstone were spongy, containing numerous small cavities connecting with each other in a tortuous way. These were supposed to be due to the dissolving out of the calcareous portion of the rock.

Sinking of Upper Portion of Shaft 4. Given the choice of two locations, the contractor chose that at location 607+50. The shaft was sunk rectangular, 10′×22′ over all, timbered with 10″×10″ wall

CONTRACT 12—SHAFT EXCAVATION.

	Dimensions, Feet.	Drills Used.	Round Drilled.		Drill Holes.					Per Cu.yd. Excavated.		Shaft Workmen. D = driller and helper. M = mucker.			Progress.		Material.	Maximum Water at Bottom. Gallons per Minute.	
					Cut.														
			Time, Hours.	Per Drill Hour, Feet.	Collars Apart, Ft.	Bottoms Apart, Ft.	No. and Depth, Ft.	First Bench, No. and Depth, Ft.	Second Bench, No. and Depth, Ft.	Drill Hole, Ft.	Dynamite.	12–8	8–4	4–12	Feet.	No. of 8-hour Shifts.			
Shaft 1	18½ diam.	3½" tripod	5	8	*11	1.0	6@ 8	9@ 6	16@ 6	4.0	1.5 lbs. 60%	12M	5D	14M	5	3	Hamilton and Marcellus shale	½	Length of holes gradually increased until 6 to 6½ ft. was made per day
" 2	10×22	3½" on bars	...	7½	12	0.0	8@10	10@ 8	10@ 8	4.4	2.2 lbs. 60%	2D 10M	2D 10M	2D 10M	6¾	4½	Esopus shale	4	
" 3	10×22	3½" on bars	...	3½	9½	2.0	8@12 4@10	10@10	10@10	5.2	3.5 lbs.	4D 3M	4D 3M	4D 3M	8	9	Helderberg limestone	25	
" 4	10×22	3½" on bars	...	3¼	10	2.0	8@10	12@ 8	12@ 8	5.6	3.0	3D 2M	3D 2M	3D 2M	6	7	Helderberg limestone	745	This progress before striking water seams
" 5	20 diam.	3½" on spider frame	...	5½	*10	2.0	6@12	8@10	21@10	3.6	1.3	6D 3M	6D 3M	6D 3M	8½	6½	H'ds'n R. shale	80	
" 5	20 diam.	3½" on spider frame	...	4½	10	3.0	6@12	8@10	20@10	4.0	2.3	6D 3M	6D 4M	6D 3M	7½	9	Shawangunk grit	80	
" 6 " 6	10×22	3½" on bars	...	6½ 3½	10 8	2 0	8@10 12@10	12@ 8 12@ 8	12@ 8 12@ 8	4.6 5.4	3.3 3.5	3D,6M 3D,6M	3D,6M 3D,6M	3D,6M 3D,6M	7 7	6½ 7	H'd'sn R. shale Shawangunk grit	35	
" 7	10×22	3½" on bars	...	6½	11	2.0	8@12	12@10	12@10	5.0	2.7	4D,3M	4D,4M	4D,3M	8	8	H'ds'n R. shale	115	
" 7	......	3½" on bars	...	3¾	8	0.0	8@8 & 8@12	12@10	12@10	4.7	4.0	"	"	"	7	9	Shawangunk grit		
" 8	18½ diam.	3½" tripod	...	4½	10	3.0	6@12	7@10	12@10	3.1	1.9 60%	4D	4D	4D	8½	8½	H'ds'n R. shale	18	

* Collars of cut holes are in a circle.

plates, 6″×8″ buntons and 2-inch lagging, and divided into three compartments. The shaft was rapidly sunk in dry limestone to a depth of 80 feet, when the 4-inch bore hole in the shaft broke forth, flowing at an estimated rate of 600 to 800 gallons per minute, flooding the shaft to ground-water level 40 feet from the surface. The shaft was recovered with the aid of an air lift consisting of a high-pressure pipe inserted at the bottom of a 10-inch Root spiral rivetted pipe which at first threw 1600 gallons per minute but with much diminished efficiency as the shaft was drained, although two more stages were added. With the aid of two No. 9 Cameron sinking-pumps the water was lowered so that a nipple could be driven into the bore hole. The shaft was allowed to fill up, and through a casing attached to the nipple the hole was grouted through a 1-inch pipe, effectually stopping the flow.

Flooding of Shaft 4. The shaft was dry until a depth of about 230 feet was reached, when the Binnewater sandstone began to yield water at a gradually increasing rate, until the shaft was making at 260 feet, 225 gallons per minute. This was handled by two No. 9 Cameron sinking-pumps. At this depth the indications were that the shaft would be very wet, and as the next round of holes was driven, they were plugged. However, one of the holes struck such a strong flow that the men had to leave the shaft hurriedly, abandoning their drills, the flow drowning out the sinking-pumps. This was Dec. 20, 1908. The shaft was flooded at this time to within 70 feet of the top, the estimated maximum flow being 600 gallons per minute.

Recovery of Shaft with Air Lift and Pumps. A long delay ensued while four No. 12 tandem sinking-pumps, each with a capacity of 450 gallons at 500 feet head, were being secured, in addition to one No. 10 with a capacity of 300 gallons per minute. By means of the air lift, the water was lowered to within 30 feet of the bottom, although this required three stages and immense quantities of air. By January 24, 1909, the shaft was recovered with the aid of two new No. 12 Cameron sinking-pumps, and the hole was plugged with a 2-inch nipple and gate valve. The gauge on this pipe indicated 75 pounds pressure. Many vertical holes were then drilled, each being plugged with pipes and valves, as water was encountered.

Repeated Flooding of Shaft and Recovery. On February 3 the discharge hose of one of the pumps broke and the shaft was again flooded. The very heavy sinking-pumps were continually causing trouble, due to the wearing out of suction and discharge hose and the breaking of pipe lines. The pumps were recovered again by the use of the air lift. An additional No. 12 pump was

PLATE 82.—Contract 12. Recovering Flooded Shaft by Aid of Air-lift. Trans. Am. Soc. C. E., LXXIII, 1911.

PLATE 82*a*.—Contract 12. Headframe and Measuring-box at Shaft 4. Water from tunnel was measured by orifice, the head on which was obtained by Friez Automatic Stage Recorder. Trans. Am. Soc. C. E., LXXIII, 1911.

lowered into the shaft. On February 10 the shaft was again flooded due to trouble with the pumps, and again recovered by the air lift and two No. 9 Cameron pumps, and the leaking holes were plugged. More holes were drilled and capped with pipes and valves, but the shaft was again flooded and not recovered until March 12. The holes indicated that within as close a distance as 18 inches from the bottom there were numerous seams open as much as 8 inches.

Grouting of Shaft. Twenty-seven vertical holes were drilled, 14 to 20 feet deep, and capped with pipes and valves, for the purpose of grouting the seams. A battery of four Canniff tank grouting machines was set up at the top with a 2½-inch pipe in the shaft and a 2-inch hose connection at the bottom. These machines mix and discharge by air and are very rapid, particularly when worked as a battery. At first, the grout leaked back into the shaft in considerable volume and it seemed that it would be necessary to place a concrete blanket at the bottom of the shaft. Various methods were tried to prevent this leakage—oats, bran, and horse manure, the latter clogging the seams and stopping most of the leakage in the shaft. The shallower holes took 2900 bags of cement, and the 20-foot holes only 60 bags. This grouting proved to be so successful that it was determined to try to grout the deeper seams, known to be porous and water-bearing.

Diamond drills were obtained and six holes sunk around the perimeter of the shaft to the Shawungunk grit, depth 360 feet. These holes were grouted but only 175 bags of cement could be forced in at a pressure of 275 pounds. It is probable that the latter grouting was only partially successful, the small quantity of grout placed indicating that the porous layers did not freely open into the diamond-drill holes, or that the grout clogged in the deep holes.

Sinking after Grouting. Sinking was resumed April 25, after a delay of four months. In the first 15 feet numerous seams were excavated containing quantities of grout. The grout penetrated the porous rock in a peculiar manner, solidly filling up some cavities and leaving others, even adjacent, vacant, but probably filled enough to prevent anything like free passage of water through the seams. The leakage into the shaft at this point was 225 gallons, which increased to 350 gallons per minute at a depth of 380 feet. The trouble with the sinking-pumps had become so frequent, due to the high lift, that it was decided to put in a collecting ring at a depth of 265 feet. The pump on the bottom discharged into the ring, whence the water was relayed to the top by two No. 12 Cameron sinkers protected by a bulkhead of timbers. At a depth of 300 feet another ring was installed with one No. 12 Cameron sinker pumping to the surface; the shaft then making 450 gallons per minute. The water continued to increase to 525 gallons at a depth of 320 feet and progress was exceedingly slow. The shaft at this time was so full of pumps and discharge lines that little effective work could be done. To add to the troubles, the water was strongly charged with sulphur, and the H_2S gas liberated attacked the men's eyes and caused abrasions to develop into running sores. It was difficult to procure men for work in this shaft and the hours of labor had to be considerably shortened.

Construction of Pump Chamber at 310 Feet. It was decided to excavate a large chamber in the side at a depth of 310 feet, to place in it three horizontal Cameron pumps of a capacity of 350 gallons per minute, 500 feet head. On July 15 the pumps at the upper ring broke down and the shaft was flooded for the sixth and last time. The shaft was unwatered by the aid of air lift and sinking-pumps, and excavation of the chamber started on August 1. This chamber was 17′×24′×10′ high with a sump of 14,500 gallons capacity. It was excavated at the wettest and most gaseous part of the shaft and square in the middle of it was a water-bearing seam which exuded a water strong enough to leave deposits of pure sulphur on the walls. The excavation of this chamber was exceedingly difficult work, but it was successfully accomplished and the three pumps installed. To relieve the heavy load on the power house, these pumps were operated by steam from three 100 H.P. boilers set up at the top of the shaft. A 4-inch steam line from the boilers to the pumps was wrapped with asbestos, felt and tin to prevent condensation and fog in the shaft. A seam at the chamber level which had apparently been partly grouted in the shaft through the diamond-drill holes, in the excavation of the chamber yielded 200 gallons a minute.

Ventilation of Shaft. To ventilate the shaft and make it possible for men to work in it, three Sturtevant blowers, two No. 35 and one No. 45, were installed at the top with 10- and 14-inch pipe lines. In addition, a chemist recommended that the sides of the shaft be sprayed with a mixture of one part chloride of lime and twenty parts ordinary lime to neutralize the acid sulphur gas. A large wooden tank was filled with this solution and it was liberally sprayed in the shaft with some effect. It was not notably successful.

The Pumps in the Chamber. The pumps in the chamber were condensing, the steam exhausting into the suction. The steam pumps worked very smoothly, giving little trouble, as they were rigidly connected with discharge lines in the shaft which in turn were permanently fastened to the timbers. Later, when air could be spared for these pumps, a mixture of steam and air was used, largely to prevent freezing of the exhaust valves. This was found to work very well.

Final Sinking to Tunnel Grade. After the installation of the steam pumps, sinking was resumed September 9, and various seams were grouted with small quantities of cement before the grit was reached. At this point the bore holes again broke out, increasing the flow from 725 to 850 gallons. This was grouted again for the last time, taking 350 bags of cement. In Dec. 31, 1909, the shaft reached tunnel grade, at a depth of 497 feet. About 150 feet of grit was penetrated, which contained numerous narrow water-bearing seams, and increased the flow to a maximum of 710 gallons. Some of it was cut off by grouting, so that when the bottom of the shaft was reached the flow was only 610 gallons. This shaft took eighteen months to sink, at an average rate of 28 feet per month, taking one year longer to sink than any of the other shafts. The highest monthly progress was 80 feet in the limestone. In all about 300 million gallons of water were pumped from this shaft against an average head of about 300 feet. When the inflow of water became great it was necessary to keep the bottom pumps in operation continuously. This was accomplished by excavating the shaft in separate halves. When blasting the pumps were moved to the opposite end and protected by a bulkhead. Water was kept off the bottom as much as possible by rings. In placing grout pipes in the holes it was difficult to get a tight fit by the use of wooden wedges, the usual method. Later, the pipes were wrapped on a lathe with a cone of flannel. This when pounded into the hole by the piston of a drill makes a very tight connection through which grouting can be accomplished.

The shaft was sunk to the depth of the large pump chamber by the S. J. Harry Co., after which, as the shaft required an entirely new plant, it was taken over, other superintendents of the T. A. Gillespie Co. completing the work.*

Lessons of Shaft 4. The lessons to be learned from this shaft are: place as little reliance as possible on vertical sinking pumps,

* A paper on this subject together with an extensive discussion was printed in the Transactions of the American Society of Civil Engineers, September, 1911, under the title "Sinking a Wet Shaft," by John P. Hogan. Much of the matter on Shaft 4 was taken from this paper.

using rings and chambers to handle all the water except that which comes in below the lowest ring. This bottom water can be readily raised by sinking-pumps, with discharge pipes only as long as necessary to reach the lowest station pump. A pump so rigged can be readily raised and lowered. The very large sinking-pumps such as those first used weighed over 5 tons and against high heads never ran at more than half their rated capacity. It was impossible to keep tight connections while running at full speed. At first a spirally riveted flanged pipe was used as a discharge, but this did not stand up, and it was necessary to use very heavy screw-joint pipes. The air lift is valuable for recovering a flooded shaft, but is very wasteful of power. It would appear unwise to timber a very wet shaft, as much better results can be obtained by concreting, the water being led through the concrete by grout pipes, and subsequently after the concrete has thoroughly set, the seams may be grouted, cutting off considerable leakage. In this contract no provision was made for concreting in construction shafts, but due to the experience here such provision was added to subsequent contracts. Grouting of well-defined seams in a shaft is of great aid and well worth trying in any case, as water is exceedingly bothersome at the bottom of a shaft. In the operation of the sinking pumps it was found that considerable trouble was given by the exhaust ports freezing. This could be obviated by using the air with a small amount of steam, as in the case of the chamber pumps described. Reheaters were tried, but they gave considerable trouble.

Rectangular Shafts and Their Equipment. Contract 12, as well as most of the other siphon contracts, specified a minimum size of rectangular construction shaft. This allowed for cages only 3′ 9″×5′ 6″. The contractor, however, was given the option of enlarging the temporary shafts if he deemed it advisable, but was paid for only the per foot contract price. He chose to enlarge the shaft to the size shown on Plate 83, the excavated area being increased about 30 per cent and the cage area 100 per cent. This probably increased the cost of shaft about $10 per foot, as it meant only that much more mucking and somewhat longer timbers to pay for and place. This additional expense was more than compensated by the increased capacity of the cages, and freedom of getting materials into and out of tunnels. In order to maintain a good average, tunneling and concreting at times has to be forced at the highest obtainable speed. For instance over the entire period of this contract an average of only 7 yards per hour need be handled by two cages, whereas at Shaft 7, during the maximum

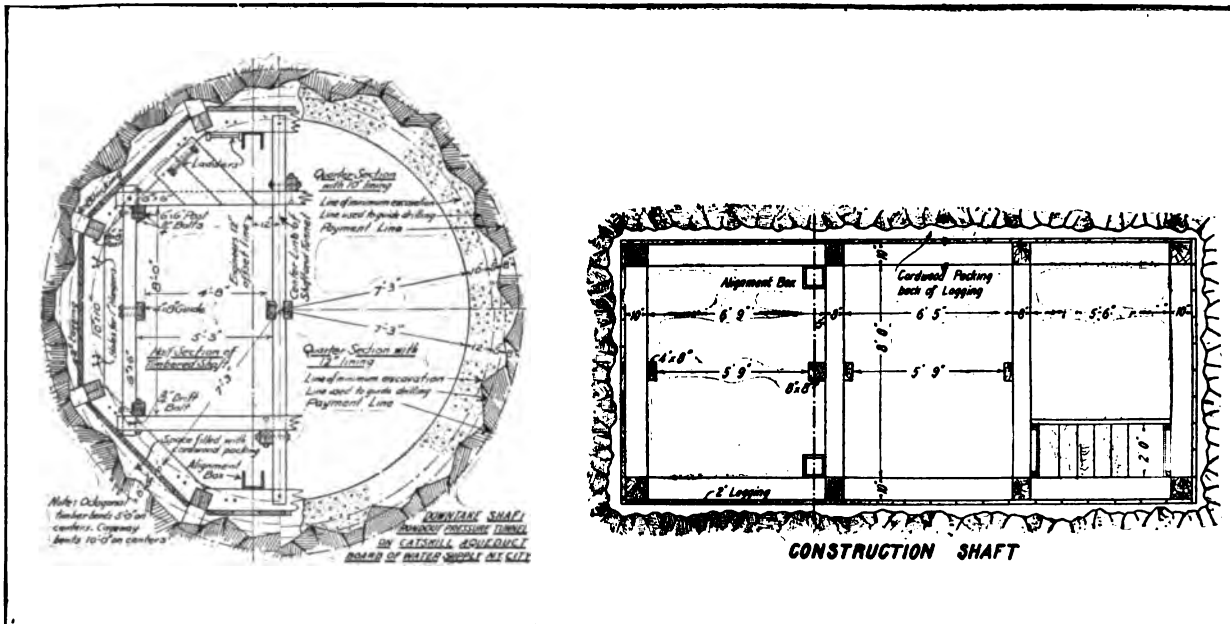


PLATE 83.—Contract 12. Cross-section of Timbering of Construction and Waterway Shaft, as Used on Rondout Siphon. Size of construction shaft and all cageways larger than indicated on contract drawings.

tunnel driving, 20 yards of muck per hour were removed. During concreting as much as 30 yards per hour were placed. At Shaft 4 the additional room was invaluable, as at times even the enlarged space was crowded with pipes and pumps. The contractors on Wallkill and Moodna siphon excavated even larger shafts than were used on the Rondout, installing also $5' \times 8'$ cages.

Circular Shaft Equipment. The contract also provided that in the three circular shafts the cages should be operated in a tower built up from the bottom of the shaft, so that the cages could be operated while the concrete lining of the shaft was being placed. The contractor chose, however, to use a much larger cage than was contemplated in the design and this feature was sacrificed. It is doubtful whether the forms for the concrete lining could be satisfactorily raised and set with the center of the shaft encumbered by cageway timbering.

Tunnel Equipment. When the shafts were sunk to grade a tunnel of about 100 feet in both directions was excavated with tunnel and shaft-sinking equipment, and the muck raised in buckets. After this, an entirely new equipment was installed, consisting of high timber head frames, below which was installed the proper cage timbering. The cages and hoists were built by the Lambert Co., the hoist being a large single-drum air-operated engine, with balanced cages, the air being supplied from the main power house. Steel side-dumping Koppel cars of 30-inch gauge were installed to carry the muck, which was dumped on large spoil banks adjacent to the shaft. After the shafts were sunk new superintendents generally took charge and organized the tunneling forces.

Excavation Lines for Tunnels. The tunnels were circular and excavated 18 feet 6 inches in diameter. In this contract an attempt was made to secure a tunnel closely driven to specified lines. With this end in view, three lines were defined, as shown on Plate 14. An A line 12 inches from the finished waterway, back of this the B or payment line, 13 inches from the A line. An examination of many tunnels by the designing division showed that well-driven tunnels broke back of the clearance line at this average distance. In order to prevent too much rock from lying close to the A line it was required that an effective thickness of concrete to an intermediate or C line lying 5 inches back of the A line be obtained. In rough rock, if points of rock only be allowed to touch the A line the desired effect will be accomplished. In a closely driven shale tunnel the excavation may closely approach the C line, in which case the contractor is paid for more than he takes out, but he is

PLATE 84.—Overwinding Device on Dial of Hoisting Engine as Used on Shafts of Rondout Siphon. Hand trips small air valve which operates cut-off valve on air line to engine. Set so as to prevent cages from reaching top of head frames.

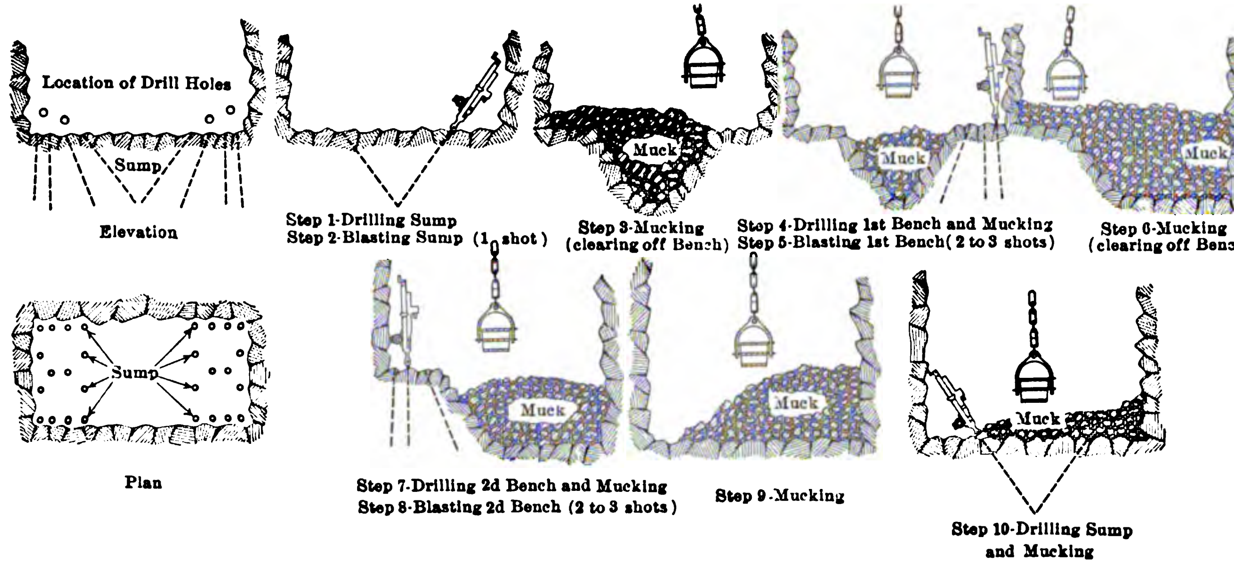
PLATE 85.—Contract 12. Various Types of Safety Dogs Used on Cages Operating in Shafts of Rondout Siphon. Lowest dog was found to be satisfactory.

thought to be entitled to this for his careful work, it being provided in all cases that he be paid the bid price for concrete and excavation to the B line. Any saving of concrete made by the contractor is shared in by the city to the extent of the cement saved. In case of excess breakage outside the B line, he is not paid for this excavation, but only for the excess concrete, and at a fixed price of $3 per yard.* As this does not yield a profit, it is not to the contractor's interest to break outside the B line. On previous tunnels much litigation over excess breakage has been the experience where the amount of breakage beyond the masonry to be paid for has not been specified. In other cases this has been left to the contractor and all breakages paid for, leading to very careless and wild work. As the contractor benefits by this it is very difficult to prevent. In the case of the New Croton Aqueduct, no payment was made for excavation outside the specified masonry lines, which led to long litigation, the contractor finally losing in the court, but securing partial payment through an Act of Legislature.

Means Employed to Secure Closely Driven Tunnel. The experience gained in the excavation of over 35 miles of tunnel in the Catskill Aqueduct shows that the payment lines are fair to both parties. On the Rondout siphon, close driving was sought for by both the engineers and the contractors. After each shot the face of the heading was carefully painted in red, the C line being used. From this the heading boss or superintendent laid out his holes. In addition, the heading was trimmed just behind the face, which was found to have a very good effect on the driving. The cross-sections by means of the sunflower was taken every 10 to 20 feet and plotted in pencil on cross-section sheets. These were shown frequently to the superintendents. Location of "collars" and "butts" of holes were also made from time to time and plotted on the cross-section to show how the holes were drilled. In this manner very accurate sections were obtained, the contractor saving considerable in excavation and concrete. For instance, the Bonticou grade tunnel, 3400 feet long, saved 856 yards over B line excavation. This, however, was very close work, and it is not felt that, ordinarily, the contractors will save much over the B line. The same system was applied to the sinking of the circular shafts, which were paid for on the yardage basis. Shaft No. 1 was drilled within the B line, the contractor saving 211 yards of excavation in 400 feet of shaft. At Shafts Nos. 5 and 8 little saving was made.

Difficulties of Driving in Circular Tunnel. In the circular

* Excess breakage is figured in stretches of 100 feet.



Material, Shales and Limestones.
No. Holes Cut 8 x 10 = 80 feet.
Bench, 12 x 8 = 96 feet.
Trimming 8 x 8 = 64 feet.
Total 28 Holes = 240 feet.
Average No. of Holes = 28 for 6¾ ft. advance.
Average Progress – One advance in 1¼ days.

Yardage per foot = 8.15 cu. yd.
Force: 3 shifts of 2 drillers 2 driller's helpers and 10 muckers.
Dynamite per advance = 120 lb.
Average rate per drill per hour.
Quarry or Shaft bar used.
Cut drilled, shot and mucked North Bench then drilled, shot and mucked. South Bench then drilled, shot and mucked. Started drilling bench before mucking of cut was finished.

SKETCH SHOWING VARIOUS STEPS IN CONTINUOUS METHOD OF SHAFT SINKING AS USED AT SHAFTS, RONDOUT SIPHON.

Plate 86.—Method of Sinking Rectangular Shafts as Used for Rondout Pressure Tunnel. Trans. Am. Soc. C. E., LXXIII, 1911.

tunnel section, the bench or lower half gives the most trouble, as this is generally taken out with vertical holes. Close results were obtained by driving a little narrow in the softer rocks and then trimming out later to exact lines with "Jap" drills. This does not pay in the harder rocks and, consequently, there is some tendency to be wide at the bottom. It was found that closeness of tunnel to lines depended more than anything else on the accurate placing of the holes and more particularly upon the direction the hole is given, so as not to bring the butts outside the cross-section.

Bonticou Tunnel. The first tunnel to be started was the Bonticou, driven from a portal at Shaft 8. The method used for driving is shown on Plate 86*a*. The same method was used on the pressure tunnels where, however, the bottom holes have to be gauged differently than here shown to form the lower half.

A short stretch at the bottom of Shaft 8 was driven by bottom heading, but was soon given up, as it proved to be more expensive.

Good Progress in Tunneling. Contract 12 was remarkable for the great amount of tunneling in progress at one time. During the week of Oct. 20, 1909, there were 11 headings in pressure tunnel in progress and one in grade tunnel, the total linear progress of completed tunnel excavated being 907 feet. The best monthly progress in all headings (12) of pressure tunnel was that of October, 1909, 3647 feet, ranging from 430 to 280 feet and averaging 304 feet per heading. For this month the contractor's estimate was one-third of a million dollars, nearly all for tunnel excavation. In each heading four drills were usually used on two columns with two drills in tripods for bench holes, all Ingersoll-Rand. During this month the central compressed-air plant furnished with apparent ease power for all the 13 tunnels, for all the hoists, pumps, etc., also electricity for light and motor-driven blowers. During this period all ten compressors were running with almost perfect regulation despite extreme fluctuation in demand, the self-recording pressure indicator cards making a circle very close to 110 pounds. By the automatic blowers very close regulation of steam pressure was also obtained.

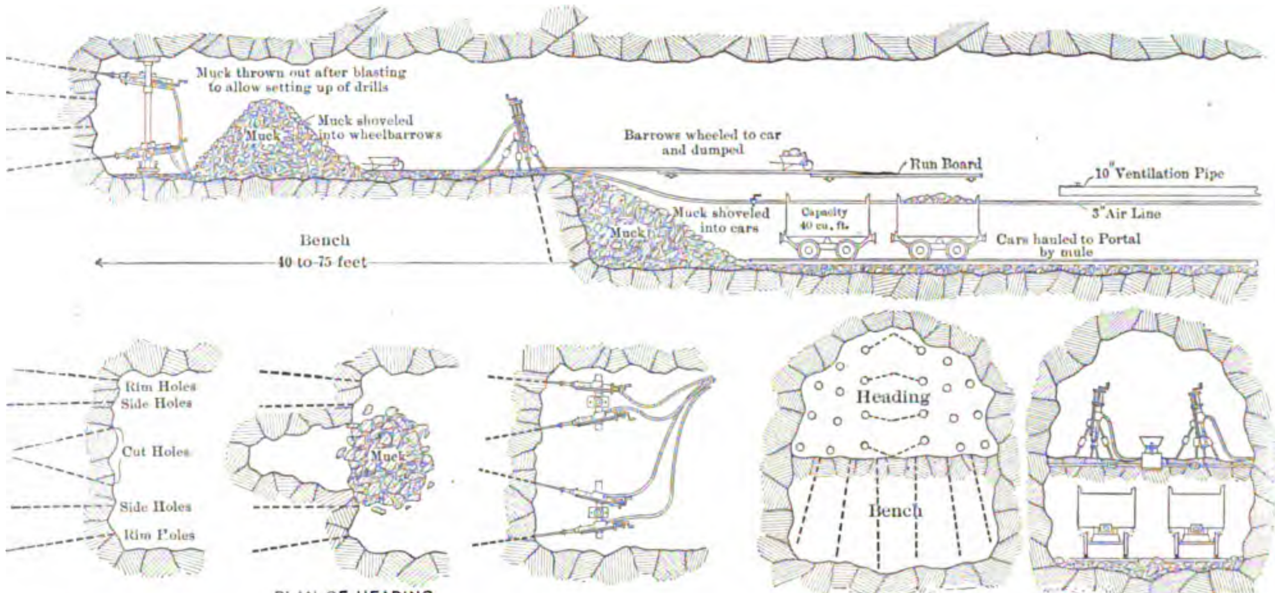
Method of Driving. Despite the individual methods of the various shaft superintendents, who were given considerable authority to carry out their own views, it was surprising how close they all came to the same standard method. Usually the bench was kept about 75 feet behind the heading. Closer than this, the muck from shooting the face hampered the work of drilling the bench. For more than this the wheelbarrow haul is unnecessarily long. From the bench the upper part of the tunnel is trimmed to true shape by means of Jap drills, barring, etc.

Although the platform, composed of telescoping pipes upon which a few boards are laid from the bench seems crude, it is really very effective, as from it the cars are directly loaded with the heading muck by wheelbarrows without disturbing the drilling or mucking at the bench, and is easily taken down and removed before shooting the bench.

Wheelbarrows vs. Mucking Machines. Numerous attempts have been made to supersede the wheelbarrow method of mucking heading, but without any marked success. The great number of headings on the tunnels of the Catskill Aqueduct gave an unrivaled opportunity to try out and demonstrate a superior method. On the Eastview and Yonkers tunnels mucking machines were used, but without marked success. At Breakneck, Hunter's Brook, and Hillview, bottom headings were used, but in the writer's opinion showed no superiority to the top heading and wheelbarrow.

Short vs. Long Bench. In some tunnels an effort was made to keep bench close to the face of heading, so that the heading muck could be shot over the bench and shoveled onto cars with the bench muck, saving wheeling and erection of platform. This had to be abandoned, as the heading rock cumbered up the bench so that the drills could not properly drill the down holes. Moreover, instead of two mucking gangs, only one could be used to advantage. Probably on large tunnels where steam shovels can be used to advantage to load the muck it pays to keep bench close to heading. Where a complete tunnel is driven by the bottom heading method the construction and moving of heavy timber platforms upon which the upper rock is shot more than offsets the advantage of eliminating wheelbrrow loaading.

Temporary Timbering. The top heading was admirably adapted to the placing of timbering necessary for about 10,000 feet of tunnel. Through these long stretches the bottom heading method would have been extremely dangerous, as a flat roof is left which is structurally weak and for which it would be wasteful to use timbers, as they would have to come out before the upper portion could be placed. Throughout most of the timbered portion three-piece timbers with 2-inch lagging packed to the rock with cordwood were used. From platforms similar to, and, in some cases, an extension of the regular platform in front of bench, hitches were cut into the rock by hand, and the timbers, cut to fit, were placed from the platforms, lagged, and packed. Where the rock was very



PLAN OF HEADING

SHOWING ARRANGEMENT OF HOLES — SHOWING HOW CUT HOLES ARE FIRED — SHOWING ARRANGEMENT OF HEADING DRILLS

SECTION OF TUNNEL

SHOWING ARRANGEMENT OF HOLES IN HEADING & BENCH — SHOWING ARRANGEMENT OF BENCH DRILLS

PLATE 86*a*.—**Diagrammatic Scheme of Excavating Bonticou Grade Tunnel, North Heading.**

bad the timber extended over the bench, but usually was placed just back of the bench. Although not expected to carry heavy loads the timbering is very strong, the hitches holding remarkably well, even in very soft rock, as the thrust of the legs tends to be outward rather than downward. They were placed within the ordinary cross-section and thus required no additional excavation, being taken down in advance of the concreting. It was predicted that this would be expensive and dangerous, but did not prove to be, as by placing half a stick of dynamite back of each leg, they were easily brought down, together with whatever loose rock had accumulated upon them. In the Wallkill siphon the timbers were pulled over by a hoisting engine.

Permanent Steel Roof Support. The pressure tunnel specifications require that all timber be removed previous to concreting, as it was feared that wood would compress and rupture the concrete lining under the enormous internal pressure of water obtained when the tunnel was in service. The contract drawings showed for ground requiring permanent support a design of steel arch ribs and L-beam lagging. In Tunnel 5 North a heavy roof was encountered where nearly level beds of shale broke away from the grit bed above. This was carried safely by three-piece temporary timbering, but it was feared that difficulty would be experienced in taking it down, so that about 135 feet of steel roof support was erected and carefully packed back of lagging with pieces of rock. The steel ribs soon started to buckle and failed in various ways, so that they had to be hurriedly posted and supported by three-piece timbers in hitches, until the time of placing the concrete arch.

Although the steel ribs were computed to be as strong as a 10″×10″ bent, they proved to be much inferior in strength. Where a roof is heavy, it is almost impossible to prevent eccentric loading on the supports. Although packed and braced carefully, the steel ribs really failed as beams, not as arch ribs in perfect compression as figured. Other heavy ground was again encountered in Heading 3 South, and an entirely different type of steel support was used. This was designed on the ground and used as shown in Plate 88. It was, however, unnecessary to use the complete section as shown, support for only part of roof or sides being required. This system proved to be very flexible and exceedingly strong, as the I-beams and timber bents can be spaced as the ground requires. It is only necessary to expose a small portion of the bad ground, which is immediately supported by the channel lagging.

Steel Support in Bad Cavy Ground. Previous to placing the concrete all the wood was removed, leaving the steel to be concreted

Plate 87.—Rondout Siphon. Five-piece Arch Timbering in Heavy Limestone South of Shaft 3. This timbering supported longitudinal steel I-beams which were concreted in with arch. Timbering was removed in advance of concrete, leaving I-beams to support roof in stretches of about 15 feet.

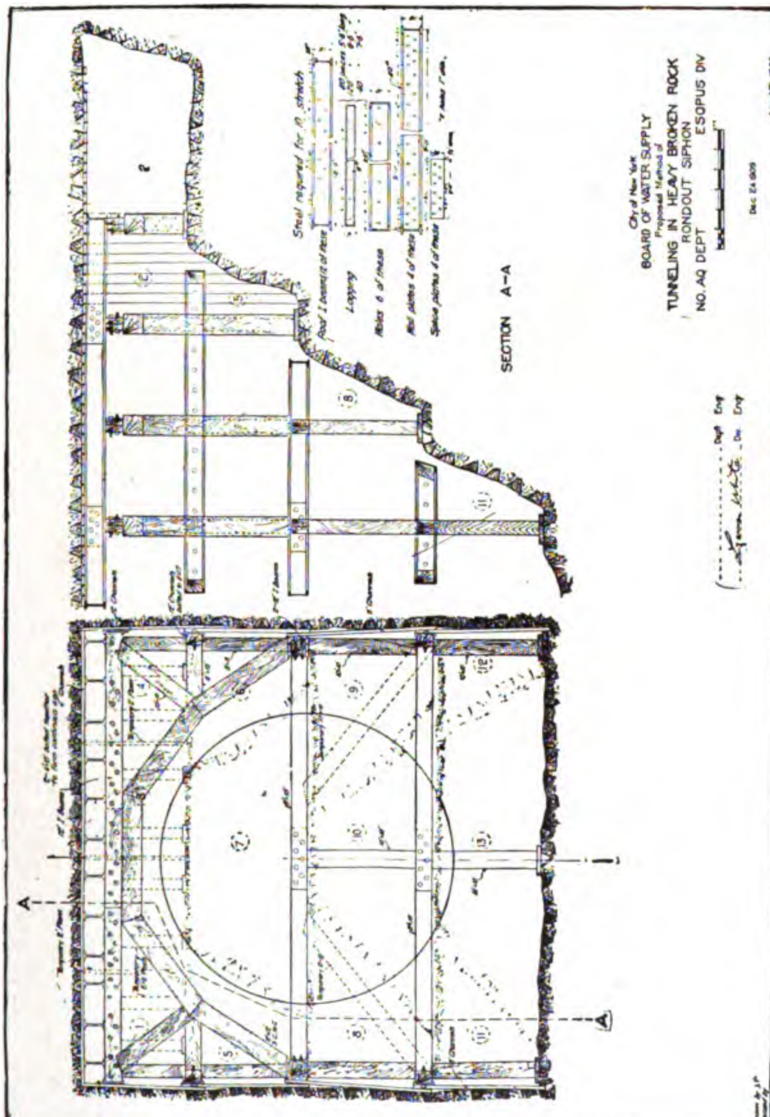


PLATE 88.—Contract 12. System of Timbering, Using I-beams and [’s Supported by Temporary Timber Arch as Used in Heavy Broken Limestone. Steel concreted in with lining, but timbers removed before concreting.

in. The longitudinal I-beams supporting the roof were designed to support a space of about 15 feet while concreting, one end of the I-beam being carried by the finished concrete, the other by timber bent not yet taken down. By the use of this method some very bad limestone in Tunnel 3 South was supported.

Driving through Limestone Caves, etc. Some of the limestone was found to be broken by faulting and solution into blocks with soft clay in wide seams between them. Some of the clay seams were several feet wide and water-bearing. At other points old limestone caves were penetrated. Those were found to be filled solidly with an impalpable yellow clay which ran freely when wet. The caves were enlarged seams and bedding planes in faulted areas, and were well defined by water-worn surfaces, as shown on Plates 89 and 90. Fortunately, Tunnel 3 South was 150 feet above the bottom of Shaft 4, which had been pumped dry nearly to its bottom together with the neighboring rocks. This drained the water from the caves so that the clay did not flow, although one vertical clay seam with some imprisoned water nearly buried the men by a sudden eruption into the heading. The roof of the horizontal clay seam in the former cave proved to be very solid, so that although a few feet high, all the broken rock was taken out below it. A top heading was driven with the water-worn surface as a roof, and the rock below excavated in several benches. The bottom-heading method through this stretch would have been very difficult and slow, requiring extensive timbering of the type used in Swiss tunnels. In addition, for two stretches, to prevent outward leakage, a heavy riveted boiler shell was concreted in with the lining. This precaution was taken although it was deemed that the concrete lining properly backed and grouted would very likely be sufficiently strong and tight. It was felt that the utmost precaution was justified in these, the worst stretches of a very difficult work.

Pumps for Tunnel at Shaft 4. When Shaft 4 reached subgrade it was making about 675 gallons of water per minute, of which only 100 gallons reached the bottom, being raised by a sinking-pump to the pump chamber, the rest being caught at the shaft chamber and intermediate levels. It was known that the wet strata encountered in the shaft would be again cut by the tunnel a few hundred feet north of Shaft 4, and preparations were made for pumping large amounts of water. A pump chamber, about 12′×12′×16′, was excavated at the foot of the shaft by enlarging the pipe compartment, and in it were placed three Cameron air pumps, two 19″×19″×12″×16″ compound, and one 18″×18″×20″ outside packed, the first two

PLATE 89.—Tunneling through Limestone Containing Water-worn Caves Found to be Filled with Clay. Note water-worn roof and clay seam below roof.

PLATE 90.—Rondout Tunnel in Limestone in which was Found Evidence of Former Caves, now Filled with Clay. Note water-worn roof of clay seams and vertical cracks in limestone.

of 450 gallons capacity and the other of 330 gallons capacity, under 500-foot head. In addition, and as was later done, it was planned to remove the three 24″×10″×20″ Cameron pumps from the

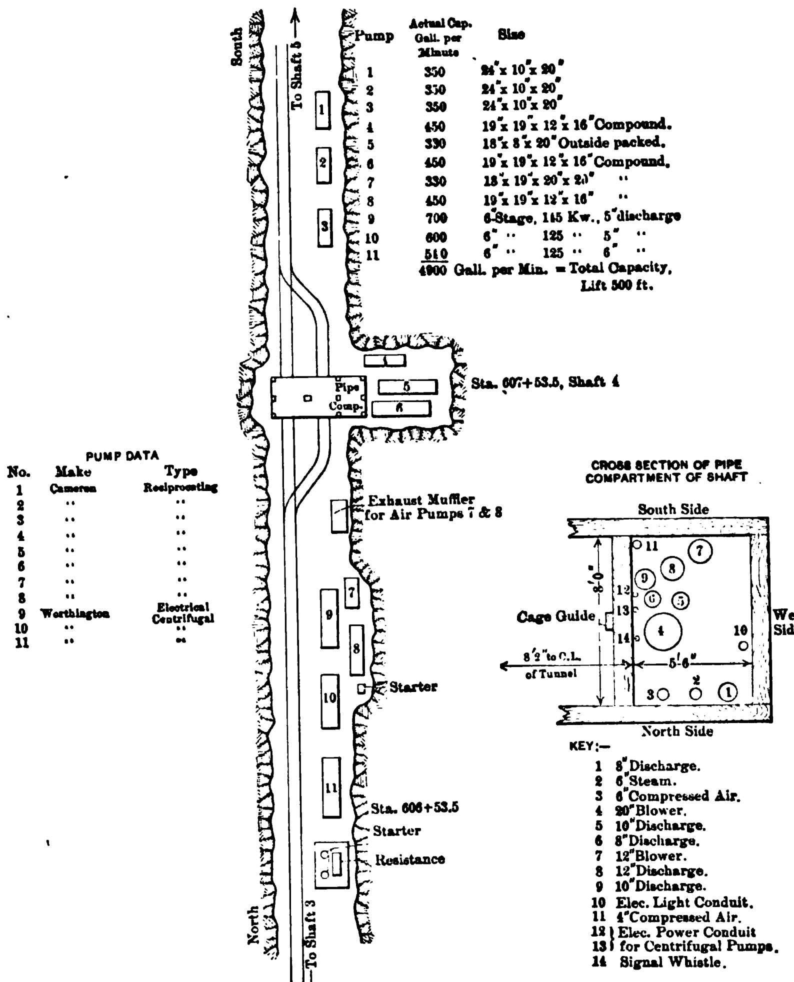


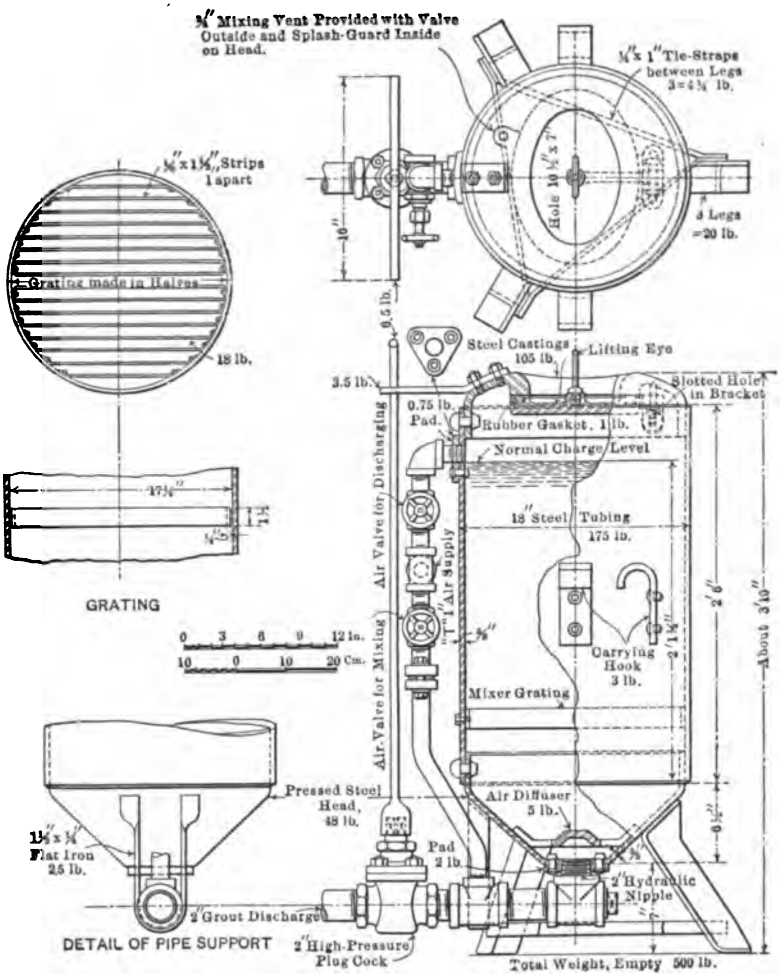
PLATE 91.—Position of Pumps and Piping Used at Shaft 4, Rondout Siphon, to Pump 1000 to 2200 Gallons of Water per Minute to Surface. Total pumping capacity about 4900 gallons under 500 foot head.

chamber to the bottom, where they each would be able to raise 350 gallons per minute to the surface. Only 575 gallons per minute were then being pumped from the chamber and the water was rapidly falling, so that before the tunnels had advanced far, the shaft was practically dry. The two 450-gallon pumps in the chamber were old sinkers weighing 9000 pounds, which proved too heavy and cumbersome, for use in shafts in vertical position, but proved very satisfactory when mounted horizontally.

Driving through Wet Shawangunk Grit. Progress in driving northward was very slow in the grit, and the water struck, at first in small volumes, contained considerable H_2S gas, which made it difficult to keep men at work, although ventilation was obtained by two Sturtevant blowers operating through 10- and 12-inch pipe lines. Finally, a seam was struck which yielded 300 gallons of water per minute from two drill holes. These holes were plugged with pipes wound with Canton flannel. Six others also reached water and were plugged in the same way. Against a back pressure of water of 85 pounds, the heading was grouted with Canniff machines operated by air at a pressure of 300 pounds per square inch furnished by a Westinghouse compressor. The water-bearing holes were found to freely communicate and 319 bags of cement were injected. This grouting cut down the water from 850 gallons to 350 gallons. Later a No. 11 Sturtevant blower was installed, pumping or exhausting air through a 20-inch discharge line and operated by a 40 H.P. engine. When shot, the water-bearing seam in the grit was found to be $\frac{1}{8}$ to $\frac{3}{4}$ inch wide and thoroughly grouted.

Trouble with H_2S Gas. Slow progress was subsequently made through the grit, which yielded at numerous places small quantities of water heavily charged with H_2S gas. The men were protected by tarpaulins overhead, and various styles of goggles were tried out to protect the eyes, and the wages of the men substantially increased. At this time the men suffered severely from sore eyes, and some complained of congestion of the lungs.

Grouting a Wet Heading. The grit was finally passed and a much-faulted stratum of the High Falls shale encountered. At first, the total pumpage was only about 550 gallons, a decrease since the tunnels started, accounted for by the fact that more water was lost by the shaft than gained in the tunnel. The shale was dry for a short distance, when the heading holes again yielded water to the amount of 300 gallons per minute. The holes were closed with pipes and grouted, but the heavy pressure used, 200 pounds per square inch, blew off 3 feet of the face of the heading, the holes being about 6 feet deep. More holes were drilled and a heavy flow met about 10 feet from the face. These holes were drilled around the periphery of the tunnel and grouted so as to dry the rock well outside of the tunnel lines. Six pipes were grouted under 150 pounds pressure, and only 30 bags of cement injected. The back pressure was 85 pounds. A third round of holes was drilled in the face and



TANK GROUTING MACHINE.

PLATE 92.—Details of Tank or Canniff Air-mixing Grouting Machine. Nearly all the grouting of pressure tunnels on Catskill Aqueduct was mixed and placed by this machine. Trans. Am. Soc. C. E., LXXIII, 1911.

grouted. The fourth round of holes was drilled, one hole encountering 50 gallons per minute in a seam 14 feet from face, another 100 gallons. These holes when grouted took 70 bags of cement at

300 pounds head. A fifth round of holes was drilled and still encountered water, the new holes spouting like fire hydrants at 85 pounds pressure.

Additional Pumping Equipment. Electrical Pumps. It was apparent that the pumping plant installed could not do the work it would be called upon to do; that in the heavily faulted and broken shale with dissolved-out irregular cavities, grouting was hopeless, and could not be expected to reduce the leakage into the tunnel materially. The contractor took radical steps, enlarged the tunnel about 75 feet from the shaft to take two more pumps of 330 and 450 gallons capacity, an 18″×19″×20″×20″, and a 19″×19″×12″×16″ compound Cameron. The power house, however, could not give air for more pumps than this, and an additional margin was required, although the air pump capacity totaled 3000 gallons per minute. Three six-stage Worthington centrifugal pumps were installed, rated as follows: 700, 600 and 540 gallons. A total installation of 8 air and 3 electric pumps of 4770 gallons per minute combined capacity. Considerable difficulty was experienced in getting a proper equipment to stand the sulphur gases in the air. The first switchboard was eaten out in a very short time. This was remedied by using starting boxes entirely enclosed, such as are used for operating trolley cars. To supply current a separate power line of 33,000 volts was run to High Falls and a transformer house equipped near top of shaft. The transformers stepped down the current to 440 volts.

Concrete Bulkhead. To prevent loss of the shaft in case of failure of the pumps, a concrete bulkhead which could be closed by a heavy wooden door was erected at the foot of the 15 per cent incline. (See Plate 93.) All pipes were concreted in and provided with valves on the outside, and a slot for the cable used to raise cars up the incline. This bulkhead proved its worth when the powder magazine at the top of shaft exploded and wrecked the transformer house and damaged the air, light and steam lines also. All the pumps were stopped when the inflow was 1650 gallons per minute. Men were sent through from the next shaft and the bulkhead was closed. The heading soon filled up back of the bulkhead, but only a small amount of water leaked through to the shaft, which was readily handled by the air pumps after they were started up. By strenuous work the electrical pumps were started up again in eighty-four hours and the heading pumped out in five hours.

Six Hundred-gallon Leak Revealed by Heading Shot. The first shot made after a shut down of about three months revealed

PLATE 93.—View of Three Six-stage Worthington Centrifugal Pumps—Motor Driven—Used in Tunnel Near Shaft 4. This pump had capacities of 700, 600, and 540 gallons per minute under 500 foot head. They pumped continuously for nearly two years from 2200 to 1100 gallons per minute.

a water-bearing crevice to the right of the tunnel very near holes which had been repeatedly grouted. The crevice, 2′×8″, was in the axis of a fold, the stratum being doubled on itself, in the sandstone, and extended indefinitely backward and upward. Into this crevice spurted innumerable streams of water, the crevice shunting the water into the tunnel like a V-shaped flume. This yielded about 600 gallons per minute, and at this place over 1000 gallons of water spurted into the heading, running swiftly down the 15 per cent incline in a leaping cascade. The total pumpage then reached a maximum of about 2000 gallons per minute, which was easily handled by the pumps. A large sump was used to settle the grit before the water was taken by the electrical pumps. However, some of them were cut badly and had to be repaired.

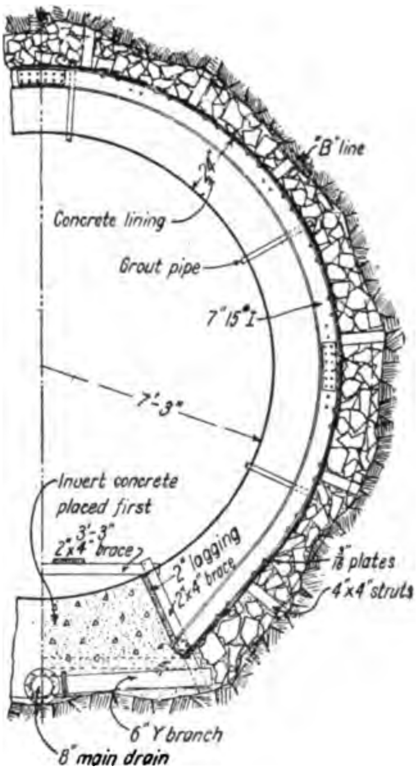
Diamond-drill Exploratory Hole. While the tunnel was shut down a diamond-drill hole was placed along the axis of the heading to explore the ground ahead in a search for caves, etc. The hole revealed little, only a small percentage of core being recovered.

Tunneling on 15 Per Cent Incline. Numerous leaks were encountered beyond the main water-bearing area in the broken and faulted shales and sandstones, but fair progress was made in the heading, which was driven ahead to connect with the heading advancing down the incline from Shaft 3.

The main leaks decreased rapidly, losing more than made by others encountered ahead. The water in the wet ground was pumped down to elevation −200 (about 50 feet above the bottom of Shaft 4) so that the heading was dry when the incline reached this elevation. It was most fortunate that this incline was situated here. Had the tunnel been carried through at a uniform elevation of −250 feet the difficulties of tunneling would have been immensely increased, as a long stretch of wet ground with clay seams, etc., would have had to be penetrated. It was found practicable to operate cars on the 15 per cent grade and drive both up and down the grade by means of hoists and cables, although the danger from runaway cars was considerably increased.

After the headings met the bench was drilled and shot and the muck taken out through Shaft 4, rapid progress being made. The inflow of water dropped to about 1200 gallons per minute, remaining nearly constant at this until finally grouted off. It is probable that the early large flows represented the accumulation of water in the underground reservoir, and that the 1200 gallons per minute of steady flow represented its normal supply.

Steel Shield to Protect Concrete. Through the wet tunnel on the incline, the section was enlarged to 24 inches to the A line in order to give a thicker concrete lining and more working room. In the stretch where 1000 gallons of water was encountered in less than 150 feet, issuing in streams from all parts of the tunnel, so as to prevent the placing of a sound concrete lining, a steel shield (designed as shown on Plate 94), consisting of overlapping steel plates supported by I-beam ribs concreted into the invert, was erected. This construction also had considerable strength to support a heavy roof, although the roof, despite being much broken up, required only light support. Under the protection of this shield the concrete was easily placed, there being very small leakage through the plates, the water being carried through the invert pipes without accumulating head. At each side of the roof support cut-off walls were constructed of brick so that the dry packing over the plates could be grouted with the water quiescent.



HALF SECTION
STEEL SHELL USED TO PROTECT CONCRETE LINING IN VERY WET STRETCH OF RONDOUT PRESSURE TUNNEL

PLATE 94.—Construction of Steel Shell for Wet Section of Rondout Tunnel.

Trimming of Tunnel. Although the contract provided that concrete lining might be required to protect poor stretches of tunnel during the tunnel driving, the headings and benches were driven through and excavated, it being recognized that to concrete and excavate the tunnel at the same time would delay the work and seriously handicap the contractor. After the headings were driven

PLATE 95.—Rondout Siphon. Steel Shell in very Wet Ground North of Shaft 4. Invert in place. Plates of interlining packed with broken stone to conduct water to drain in invert. Many springs were led directly through pipes to facilitate grouting.

through and the benches excavated between shafts the muck under the tracks was excavated and all rock within the prescribed lines taken out. It was found best to start this work at the shafts, working toward the center in order to give drainage. The difficulty of driving a circular tunnel was here revealed, as in order to get room for the tracks it was necessary to allow 1 foot or more of material to remain in the bottom. For considerable stretches it was found that the bottom holes did not pull as low as expected, so that the lowest excavation had to be taken out as a sort of sub-bench. As the concrete lining of the tunnel has to withstand great internal pressures, all loose rock shattered by blasts was excavated. Where holes had been placed too deep this considerably increased the excavation necessary. On solid bottom a new track was laid and subsequently used for concreting invert, etc. It was found easy to enlarge the shale tunnels to the required lines, when driven narrow. This proved to be slow work in the hard rock such as the limestone and grit. The roof was generally high enough except for one stretch where the bottom of the grit bed was allowed to come down into the tunnel. This could only be taken out by large drills, as Jap drills were unable to put holes into this rock and the harder limestones. The experience gained by the contractor on the first stretches trimmed was such that later great pains were taken to excavate all hard rocks so as to leave little trimming, and particularly not to allow any high bottom.

Concreting of Tunnel. The work reached an entirely new stage when the concreting started. Previous to this a road had been constructed over the right of way connecting all the shafts, but making use in a few places of stretches of public road. In some instances rather deep cuts and fills were necessary. This road was a great convenience for hauling supplies, etc., but it was recognized that it would be very expensive to haul the concrete materials by wagon over these roads with their very steep grades.

Aerial Tramway. A Roebling aerial tramway was installed, operating from Shaft 5 to Shaft 2. This tramway was about 12,000 feet long and was supported on towers from 10 to 45 feet high placed about 300 feet apart, with one 800-foot span at Rondout Creek. An air-operated engine hauled the endless traction rope at a speed of about 350 feet per minute, the buckets placed about 200 feet apart running on fixed cable on top of the towers.

The Quarry. At the loading station just beyond Shaft 5 a large McCulley crusher plant was erected. At a distance of about one-half mile a quarry in the Shawungunk grit was opened and the rock

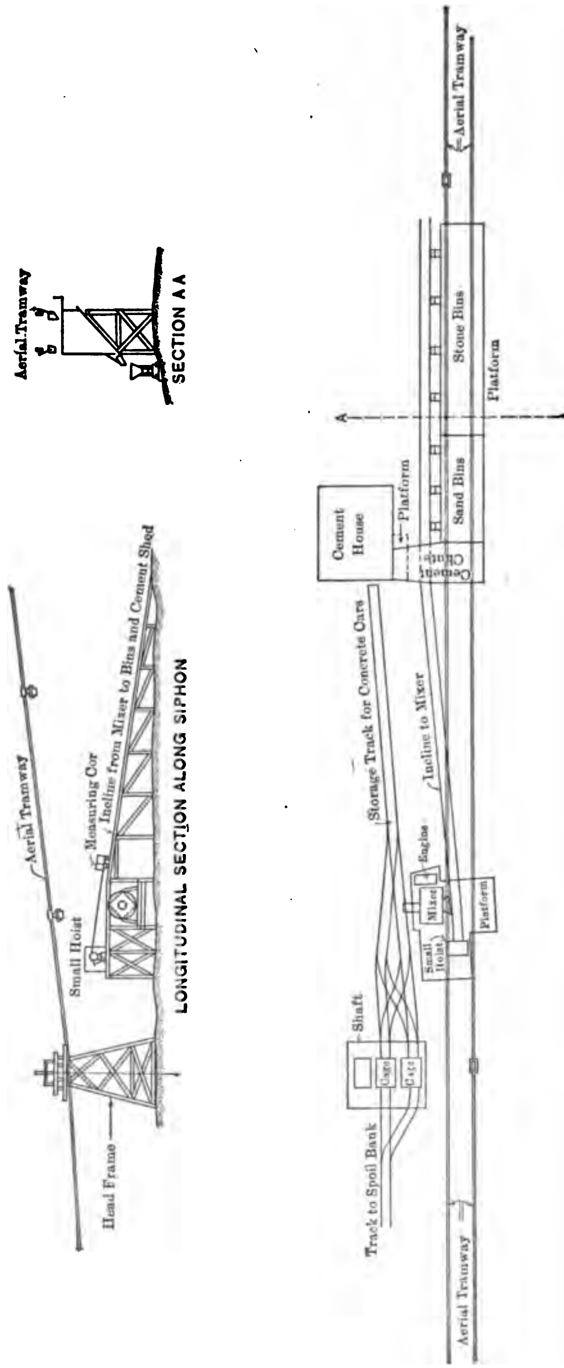


PLATE 96.—Rondout Siphon. Roebling Aerial Tramway Used to Transport Cement, Sand, and Stone between Shafts 5, 4, 3, and 2. Arrangements of bins and concrete plant at shafts.

from this quarry hauled up a trestle and dumped into the No. 8 crusher. The drills at the quarry were supplied with air from the central plant and the rock loaded into the cars by derricks. Owing to the hardness and refractory qualities of the grit the operation of this quarry was rather expensive, particularly so as a great deal of stone had to be sledged or mud capped to a small enough size to pass through the crusher. The experience here and at many other points was that it would have paid to install a much larger crusher to save this sledging, even though of much greater nominal capacity than required. The plant was also equipped with sand rolls, but these were not found profitable to operate, the cost of repairs being too great.

Sand Pit and Operation of Tramway to Supply Concrete Materials. A very good sand pit was discovered near the stone quarry and a track was laid so that the cars could be filled by hand. These cars were brought to the stone crusher and the sand elevated to bins adjacent to the crushed-stone bins of the central plant. The buckets of the aerial tramway passed underneath these bins and were filled with stone and sand as required. At each shaft the tramway passed over sand and stone bins so that the buckets could be dumped into them by a man releasing the catch. At the crushing plant the buckets could also be loaded with cement hauled from the central storehouse adjacent to the O. & W. railroad. The tramway therefore supplied four shafts, 2, 3, 4 and 5, with all necessary concrete material. This plant was so economical and successful in operation that the contractor regretted not having installed it earlier, as he thinks it could have been used for handling timber and general supplies, and also that it could have been readily extended to take in Shafts 5 and 7, and perhaps also the terminal Shafts 1 and 8, which, however, would have been more difficult to reach on account of the steepness of the adjoining slope.

Concrete Plant at Shaft 1. At Shaft 1 the only concreting done was the lining of the shaft and a small stretch of tunnel. A small crusher was set up here and fed with field stone gathered from neighboring stone walls. The sand was hauled from a neighboring sand bank and the cement from the storehouse at Shaft 2.

Concrete Plant for Shafts 7 and 8 and Bonticou Tunnel. Between Shafts 7 and 8 a quarry in grit was opened and a crushing plant erected similar to that at Shaft 5. Tracks were laid from this plant to bins at Shaft 7, the cars of crushed stone being dumped directly into the bins by means of an overhead trestle. They were hauled up the steep grade to Shaft 8 by means of a cable

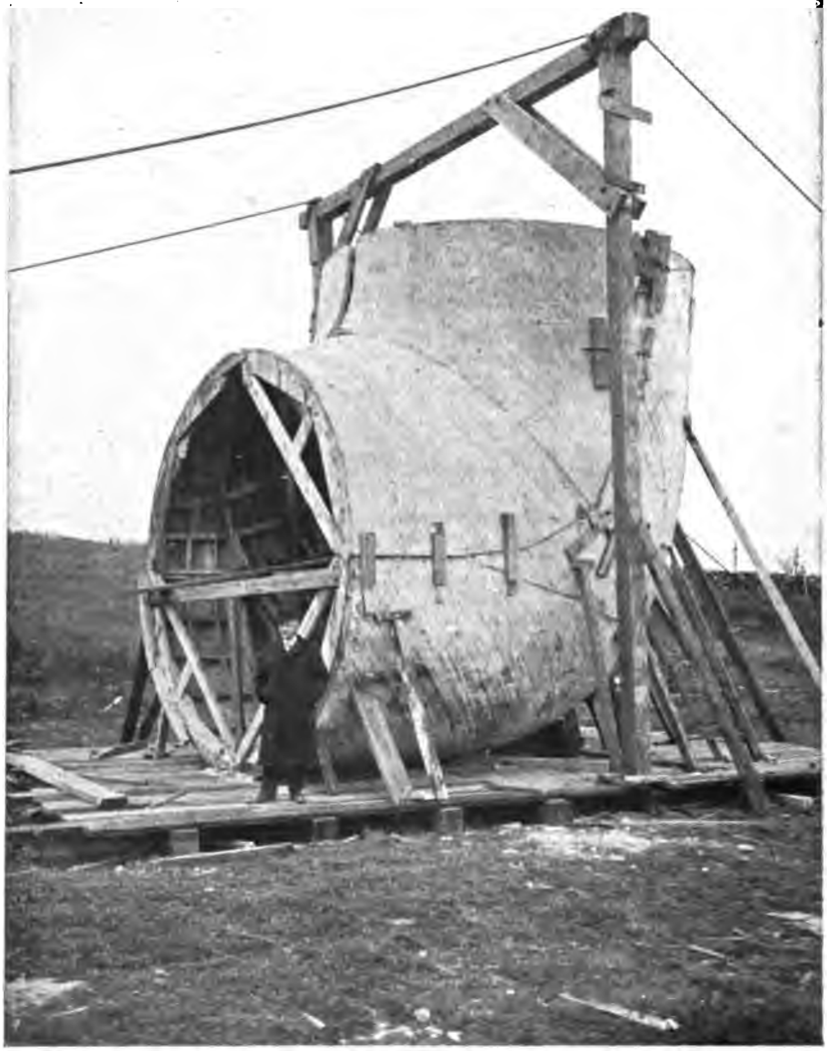


PLATE 97.—Rondout Siphon. Wooden Quarter-bend Form for Bottom of Downtake and Uptake Shafts. Terminal sections are 14′ 6″ in diameter. Form is parabolic on center line.

and dumped into the bins used to supply concrete to Bonticou tunnel and the lining for Shaft 8. Sand and cement were hauled by wagons to Shafts 6 and 7 and to the foot of the incline at Shaft 8. With the plants above described no difficulty was experienced in furnishing sufficient concrete material. Due to the hardness of the grit the wearing parts of the gyratory crushers, though made of manganese steel, had to be frequently replaced.

Concrete Mixing Plants. At the portal of the Bonticou tunnel a Smith mixer was installed which was charged by measuring cars filled directly from the bins. At the other shafts Chicago cube mixers were installed. Some of them were equipped with self-charging devices. These were not found to be satisfactory and were taken off, the mixers being charged directly from measuring cars filled at the bins. These cars were operated on inclines by small rotary air engines and cables. The measuring cars were end dumping, subdivided into sand and stone spaces by hinged diaphragm. These proved to be very handy and gave an accurate measure of the concrete material. The concrete cars were side-dumping Koppel and Youngstown, holding about 22 cubic feet. They were run on the cages from the mixer and hauled to the forms by mules.

Concreting of Tunnel with Full Circular Forms. The concreting of so many miles of circular tunnel under the rigid specifications governing this class of work presented new problems in construction. To give a start for lining Shaft 8, Blaw circular steel forms were ordered. These consisted of channel ribs, 5-foot centers, upon which were bolted steel plates. The concrete pedestal blocks were set to proper grade, upon which the steel forms were erected and a 30-foot section successfully concreted in one operation. This was seen to be very expensive, as the forms had to be taken down by hand and set up piece by piece. It was also found not to give very good work, as it was hard to get the concrete to flow beneath the forms. The contractor then devised a new method which proved very adaptable to the work, cut down the cost and increased the progress. This method, which is given below, has been followed in nearly all the pressure tunnel contracts on the aqueduct. The concrete was placed in three stages, invert, side walls, and arch.

Invert Concrete. After cleaning all muck from the bottom and exposing the solid ledge, continuous wooden forms were placed for a 5-foot wide invert. These side boards were set on a radial line tied together with ties and spreaders and braced down. They had a depth equal to the average required thickness of concrete lining.

At first the plane of the side boards was carried down into the low point by short boards. This was later simplified by allowing the concrete to fill the bottom level to the base of the side boards, whence it was formed into radial shape by the side boards, thus filling up many holes with concrete which otherwise would accumulate muck and be hard to clean out when the side forms were set. The concrete was usually placed by dumping the cars onto a platform, where it was shoveled into wheelbarrows which dumped from a runway directly into the form. When the forms were filled the concrete was shaped up roughly with shovel, and as it stiffened was worked to the required

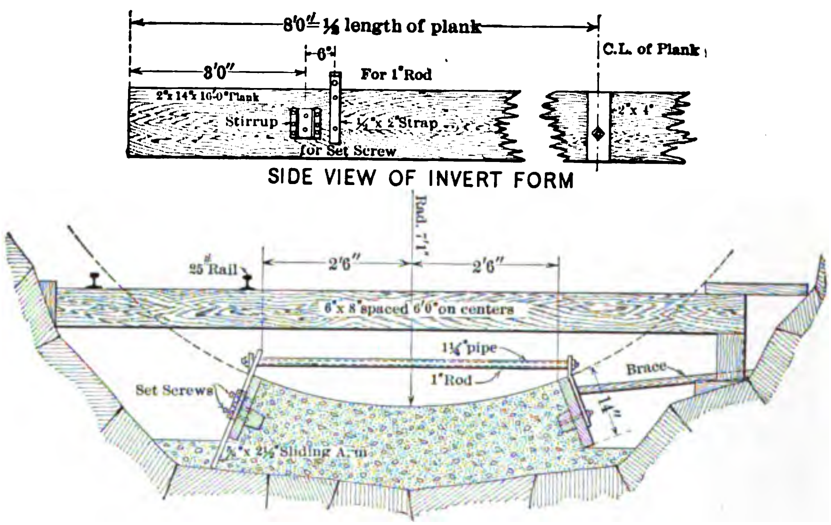


PLATE 98.—Details of Continuous Invert Form for Pressure Tunnels. Also "high line" for placing concrete directly from cars.

curve by the use of screeds and trowels. The progress per day varied from 75 to 250 feet, depending mainly upon getting the bottom mucked out and the forms set up. The concrete was all placed by the day shift, the other two shifts being used for mucking and setting forms. Owing to the fact that the pressure tunnels were mostly on very flat grade without subdrains, the damming off of the sections, installing of pumps, and a thorough cleaning of the bottom preparatory to placing invert represented a great deal of work. On the Rondout siphon, the invert was mostly placed from wheelbarrows, but on the Wallkill siphon, owing to the electric locomotives, there used, the cars could be hauled up slight inclines and dumped directly

PLATE 99.—Screeding Invert for Rondout Siphon. Concrete was laid between continuous forms held in position by pipe spreaders. Skip is 5 feet wide with radial side joints and bonding grooves.

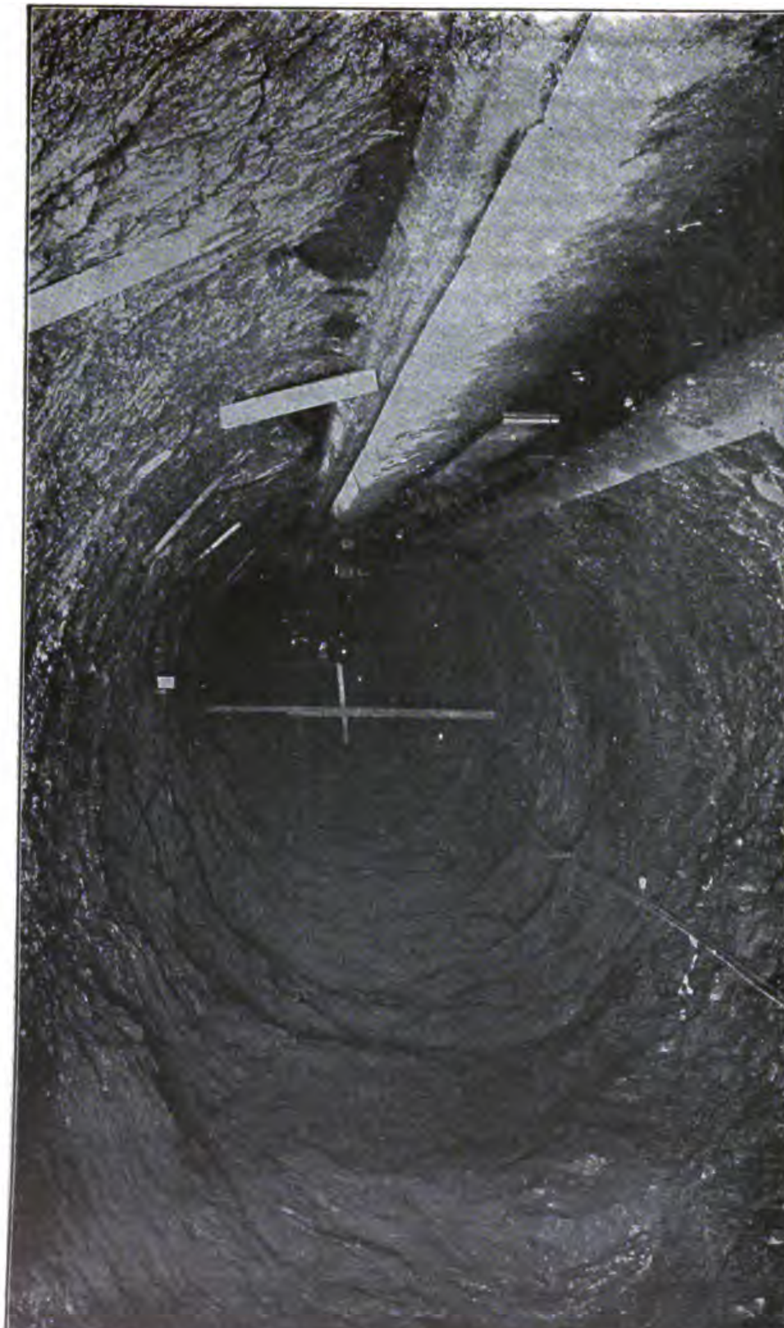


Plate 100.—Contract 12. Trimmed Tunnel in Hudson River Shale and 5-foot Strip of Invert as Laid for Rondout Siphon. This invert affords a foundation for tracks and forms.

into the invert, thus giving greater progress. Forms and method of placing invert are shown on Plate 98.

Side Wall and Arch Concreting. At first it was planned to start side walls as soon as a sufficient stretch of invert was laid. Later it was found much better to complete entire invert between shafts before setting side-wall forms. The side-wall forms were constructed by the Blaw Company, and as originally made were composed of semicircular ribs and plates set directly on invert concrete, as in the case of the complete circular forms first described, they were to be taken down piece by piece and reassembled. As this was slow and expensive the contractor devised a method by which the forms could be made collapsible in 60-foot units. The top braces were cut and turnbuckles inserted so that the sides could be sprung away from the concrete. The forms were also mounted on wooden carriages running on beveled wheels on the invert. Small screw-jacks on these carriages raised and lowered the forms by means of the bottom braces. For constructing arch these forms were turned over and mounted on high wooden carriages running on rails. On later work the arch forms also ran on beveled wheels on the invert. These forms are well shown by Plates.

To reach the concrete platform at the level of springing line of arch, an inclined track about 70 feet long was built, so as to be readily moved on trucks. The cars were hauled up this incline by an air-operated engine placed ahead of the forms. During the first season's work the side-wall concrete to the springing line was first placed, and after a section of the tunnel side wall between adjacent shafts had been completed, the forms were reversed, and in same stretch arch was placed.

Progress Made in Concreting Sidewalls. In order to allow the concreting of a section of side wall every day, three sets of forms 60 to 80 feet in length were set up, so that with them a space of one-half the distance between shafts could be concreted. While a form was being filled, another was struck and moved. The forms were so arranged that the mules could pull concrete cars through them. It was usually easy to fill a form in a few hours, but it was difficult to get one ready for filling every day, due to the amount of cleaning necessary around invert. In wet tunnels this could only be accomplished by the formation of temporary sandbag dams and considerable pumping. The forms were allowed to be struck within twenty hours after being concreted. Wooden bulkheads were used at the ends of the sections with a key to engage the next section. Longitudinal keys were also cast at the top of the side wall to engage with the arch

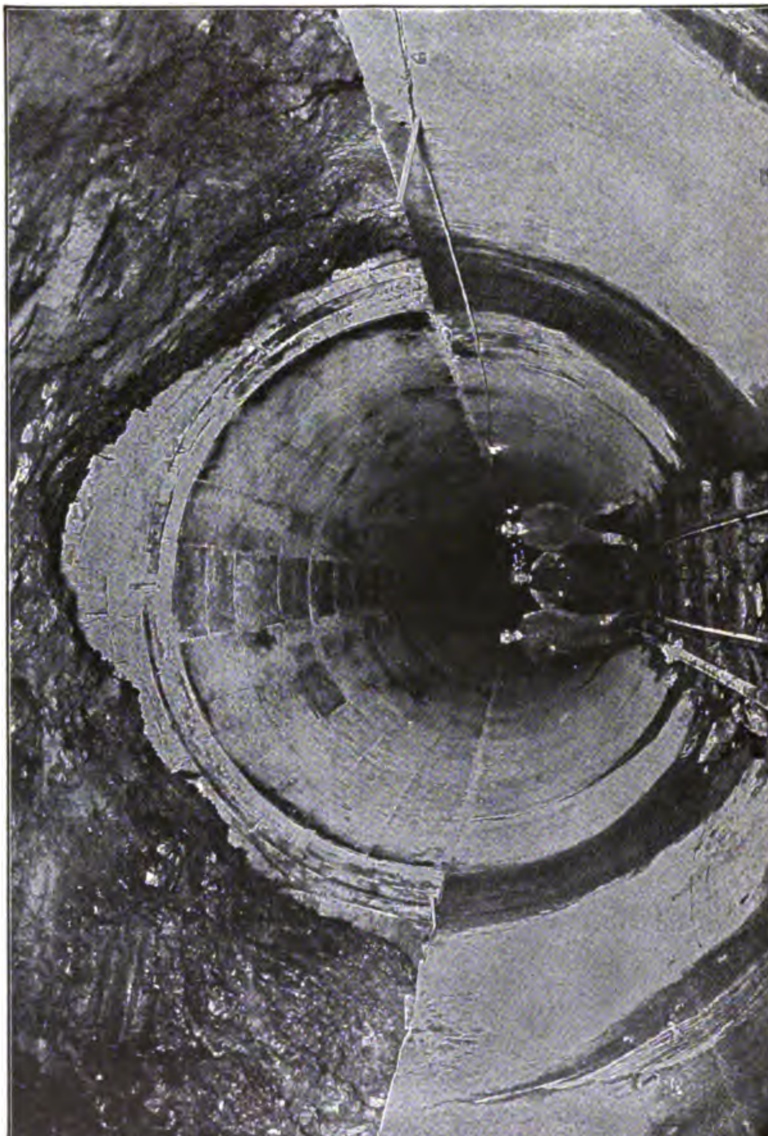


PLATE 101.—Concrete Lining of Rondout Siphon. Side walls were first placed to springing line. Above this, the arch. When possible, concrete was placed against solid rock. Note grout pipes in key.

above. After a form was struck it was readily moved forward by the hoist used to raise concrete up the incline. The maximum weekly progress of the side walls for the whole contract, with concreting in progress between five pairs of shafts, was 1175 feet. The maximum weekly progress for any one stretch of tunnel was 452 feet with three sets of forms, two 60-foot lengths and one 80-foot length, between shafts 2 and 3. The best monthly progress in side walls between these two shafts was 1770 feet, concrete being obtained from both shaft plants.

Method of Placing Arch Concrete and Key. The forms used for side walls were turned over and employed for arch work, mounted on a specially designed carriage running on a pair of rails, carried on 6″×6″ in timbers laid on the invert, the rails being spaced by 6″×6″ ties 5 feet apart. The same inclines were used to bring the concrete up to the platform at the springing line. The cars were dumped on the platform and the concrete shoveled by hand into the back of the forms, all plates of the form being in place except a few at the top, the rest of the arch panels being added as the concrete was placed. For watertightness a very wet concrete was used, making it necessary to use radial boards to form the arch key. These boards were placed next to the key-plates, and the concrete banked up above these as steep as it would stand. For the first 10 feet the key-boards were not necessary, as the concrete could be cast directly in place over the plates. As soon as the concrete obtained a slight set the key-boards were taken down, and from a temporary platform 3½ feet above springing line the concrete was shoveled into the key, key-plates being placed from one end. The time required to place a 40-foot section of arch was from eighteen to thirty-six hours, the average about twenty-two hours, a considerable portion of the time being taken up in placing the key.

Concreting Arch without Key-joints. Where the roof was low, a method was sometimes used in placing the arch concrete, so as to avoid the use of the key-boards and radial joints. The concrete was shoveled back of the forms in the usual way until about one-half of the arch is placed and then brought up on a sloping line, a portion of the key concrete being placed by casting over the form which was completely erected next to the completed lining. Concrete was added along this slope so as to keep it always in a fresh condition unset, the 2½-foot key-plates being added gradually. In this manner the concrete arch was carried up as a monolith.

Progress Made in Arch Concrete. The concreting of arch proceeded until the forms met, when it was necessary to make a

PLATE 102.—Rondout Siphon. Steel Arch Forms and Wooden Carriage for Pressure Tunnel. Carriage runs upon rails—form clears concrete by pulling in sides with turnbuckles and lowering carriage by small screw-jacks.

closure in the key. This closure was first made by the use of wooden boxes, the concrete being placed in them and rammed in place by a sort of crude piston. This was not found to give a very good job, so that another method was devised. This was, however, not a matter of great importance, as these closures were only required at intervals of about 1000 feet. The maximum weekly progress of arch for the whole contract was 803 feet, working between five pairs of shafts. The maximum for any one stretch of tunnel was 354 feet between Shafts 2 and 3, using five 40-foot forms.

Method of Concreting with "Trailing Forms." Although the method of concreting in three stages was found to be efficient and handy, the concreting of the key was necessarily slow and expensive, as only a few men could be employed at this, requiring, however, the whole concrete plant and transportation system. To secure greater economy with an increase in speed, a new method was devised the second season and used wherever practicable on the Rondout and other siphons. This method was known as the method of trailing forms. A semicircular arch form and side-wall form are kept close together, the platforms adjoining and served by a common incline and track. One large gang of concrete men was used under one foreman. The concrete is used as rapidly as possible in the arch form, the surplus cars being dumped in the side-wall forms which serve as a reservoir, the concrete being mixed and taken to the forms as rapidly as possible. Usually by the time the side-wall form is filled a part of the arch is keyed up and a small gang is left to finish the keying, or toward the ends the concrete may come slower so that the keying up and the side walls are finished at the same time. By this method the expense of keying is very much reduced.

Special Concreting at High and Wet Sections. On the Rondout siphon there were not many stretches where straightaway concreting could be done, as there were many wet stretches and specially large places requiring timbering to be passed. Where the roof broke high, it was found to be better practice to put in as much concrete over the form as it was practicable to place and filling the remaining space with dry packing to be grouted later. This was slow work, requiring the placing of a large amount of concrete above the tops of forms. In wet sections the water was very carefully led through the forms by means of drip pans and grout pipes, the grout pipes acting as weepers.

Drip Pans and Weepers. Where a section of rock wall was found to be dripping a pan of sheet iron was placed over this area, the edges being caulked with oakum. This pan connected at its low point with a 2-inch pipe led through the form. Where the pan was likely to be ruptured by the pressure of the wet concrete, it was backed with broken stone. It was found that neglect in providing for the free outlet of water led to porous concrete, for as soon as any head accumulated against the green concrete the water would force its way through. In the wet sections considerable areas had to be so covered, and the placing of drip sections and grout pipes was a large part of the work preparatory to concreting. The care taken to provide for water was amply rewarded, as many long stretches through wet ground showed no leaks through the body of the concrete, the water all issuing through the grout pipes. To reach the space formed by the shrinking away of the key concrete from the roof, pipes were placed at frequent intervals directly on top of the arch. At specially high points long pipes were inserted to act as vent pipes to allow the escape of the air when the lower pipes were grouted. The specially wet section north of Shaft 4 was concreted beneath a steel plate protection, as described before.

Concreting Shaft 8. Shaft 8 was the first to be concreted, no cages being placed in this shaft, the tunnel from 7 to 8 being driven from Shaft 7. The shaft was 710 feet deep, and was lined from the bottom up, the timbers previously placed being removed in stretches of 50 to 100 feet in reverse order as placed. The Blaw steel forms were used, made up in 5-foot panels in quadrants. They were internally trussed and collapsed by pulling out a wooden key. The average progress made in placing concrete lining and removing timbering was about 5 feet per calender day.

Concreting Shaft 1. Much better progress was made at Shaft 1, with the same forms. As in Shaft 8 concrete lining was alternated with the removal of timbering, which was here taken out in stretches of 60 feet to 120 feet at the rate of 30 feet per day. A very efficient little concrete plant was here installed. Stone from the bins of a small crusher was wheeled to the charging hopper of a Chicago cube mixer, together with the necessary sand and cement. Small flat cars containing bottom-dumping Steubner buckets were run alongside the mixer and the buckets filled. The cars were then run on two counterweighted doors over the shaft, the bucket hooked and lifted part way into the head frame, the car run off and the doors opened, so that the bucket could be lowered into the shaft. The doors immediately closed, a cable operating in a slit between the doors. To each door one rail of the track was spiked. This arrangement was very rapid and very safe, as the top of the shaft was protected at all times except for the short intervals when a bucket was near the top. All concrete was readily placed on the day shift, the forms being set on the two night shifts. At first the lining was done in 15-foot sections, later in 20-foot sections. Even longer stretches could have been readily concreted, but the forms proved incapable of standing the pressure of any greater length. Including the quarter bend at the bottom, this shaft, about 600 feet in depth, was untimbered and concreted in seventy-five days elapsed time, or at the rate of 7½ feet per calendar day. Excluding quarter bend and bell-mouth the average progress was 9 feet per calendar day. Concreting was in progress only thirty-three days, or 165 hours. The shaft was very dry, making only one gallon of water per minute, and therefore interfering with the concreting very little.

Concreting Shaft from Bottom up, vs. Concreting from Top Down. It is a decided disadvantage to concrete a shaft from the bottom up, as comparatively little water will form a heavy rain at the bottom of the shaft, greatly inconveniencing the men in setting forms and placing concrete. On the other hand, if a shaft is concreted during the sinking, water can be shut or led off so that the concreting of shaft lining at the greater depths is not inconvenienced.

Concreting Shaft 5. Concreting at Shaft 5 was quite a tedious operation, as it required an outer and inner lining, the outer lining being placed similarly to that at Shaft 1. The forms used at Shaft 1, 14 feet 6 inches in diameter, were adapted to the outer lining of Shaft 5 by the use of fillers. After the outer lining was placed, 2-inch vitrified tile was laid against this and waterproofed, and by the use of a new interior form the inner lining was cast. This form contained accurate castings to shape concrete guides to be used later for the floating pumping plant. The concreting of the inner lining was necessarily slow and tedious, but averaged about 7 feet per day.

Grouting Cut-off Walls. During the first concreting of the arch, a cut-off wall of concrete was carefully placed in every section, at a low point in the profile, and the arch was caulked with oakum and mortar at the end of a day's work. This was specified for the purpose of grouting short stretches of arch under pressure. In every case, where possible, the concrete was placed solidly to the roof, dry packing being used only for exceptionally high places. It was realized that the settling of the green concrete away from the roof would leave plenty of grouting space, and that dry packing was unnecessary for this purpose.

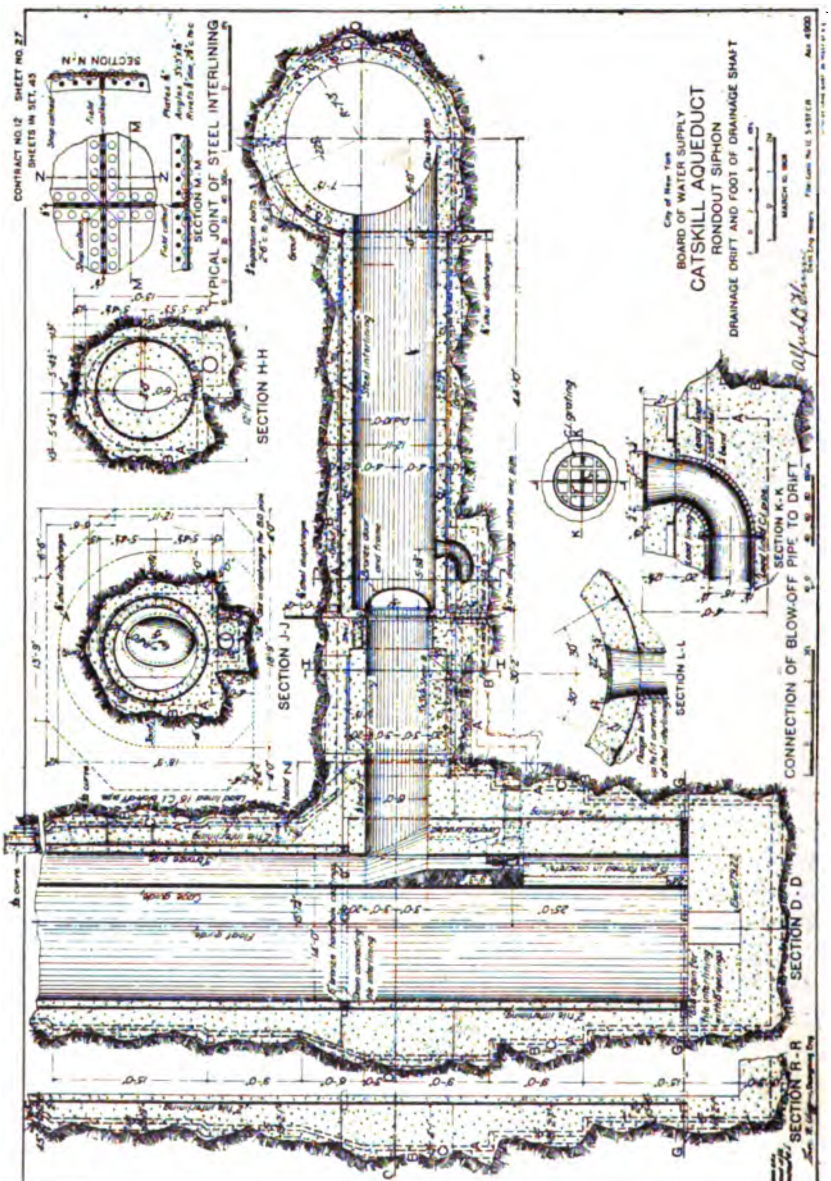


PLATE 103.—Rondout Siphon. Construction of Drainage Drift and Foot of Shaft.

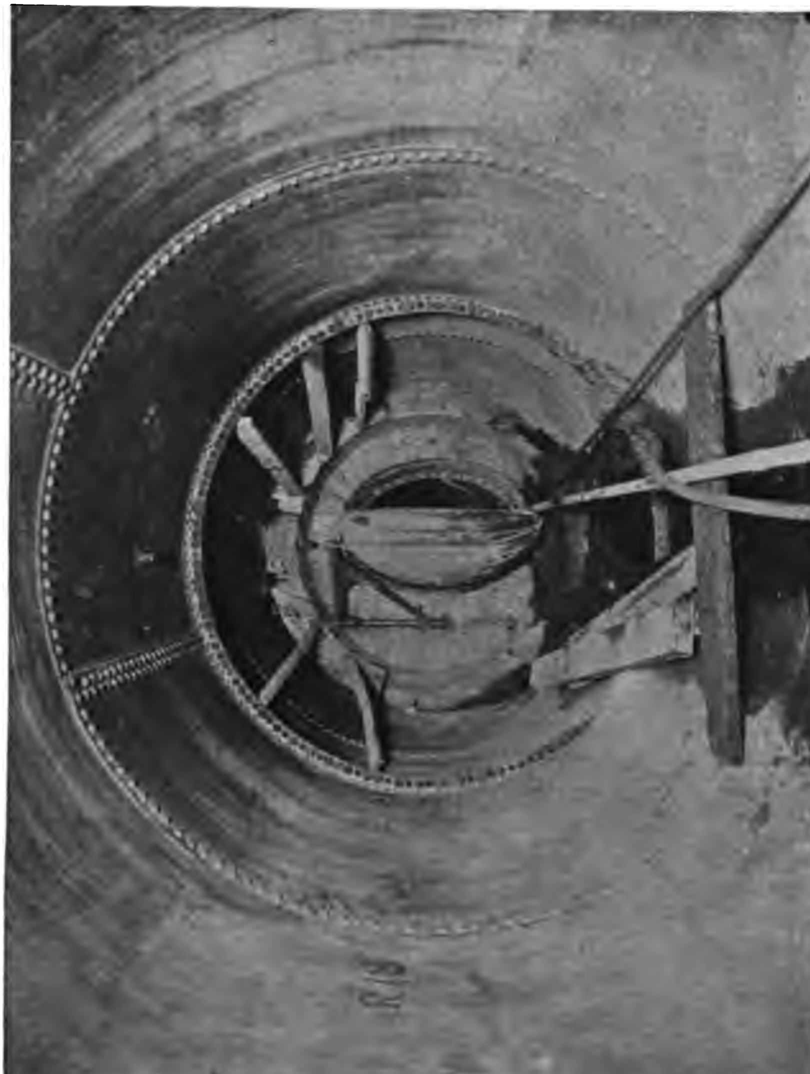


PLATE 104.—Rondout Siphon.—Steel Interlining in Drift at Foot of Drainage Shaft. Bronze access door closing drift and tunnel.

Grouting Equipment. The contract provided that the grouting was to be done up to a pressure of 300 pounds. To raise the normal pressure of 100 pounds to 300 pounds, Westinghouse high-pressure air pumps were used to supply air to operate the Caniff tank grouting machines. Westinghouse pumps and a battery of two or three Caniff grouting machines were mounted on a car, back of which were other cars containing sand and cement. The whole outfit was hauled along the tunnel track as necessary, by cable and hoist. The grouting car contained platforms from which connections could readily be made. By this apparatus the grouting could be rapidly done.

Methods of Grouting. It was soon found that the cut-off walls did not cut off, and that grout passed through them somewhat freely, probably passing through small fissures in the rock next to the concrete and between the concrete and the rock. After attempting to follow out the original plan, which provided that the sections should be put under high pressure one at a time, forcing the grout into the surrounding rock, and thus filling up all voids and stopping leaks, low points in the rock profile of the roof were selected and filled with grout, using pressures as low as 40 pounds, it being found that higher pressures threw the grout too far and discharged too much air over the arch. After these stretches were set, the intermediate spaces were filled under pressure of 100 pounds, using the low pipes until the highest ones overflowed. The high vent pipes were then cleaned so that the last remaining spaces could be grouted under pressure, which in this case was run up to 300 pounds. It was felt, however, that these high pressures were obtained only on small sections adjacent to these pipes. Tests made by cutting into the roof and into the dry-packed sections showed that the space between the roof and arch was apparently solidly filled with grout, which, however, had a somewhat laminated appearance due to the separation of sand and cement used in the proportion of about 1 to 1. This grout when set weighed about 134 pounds per cubic foot. Dry packing was found to have from 45 to 59 per cent voids which took grout. The cost of dry packing plus the grout necessary to fill its voids was somewhat more than solid concrete. It was found that the pipes which opened to the rock below the top of the waterway could be grouted individually under high pressures, the grout seldom communicating from one to another. They seldom took more than enough grout to plug them. This is supposed to be due to the fact that green concrete tends to press against the rock below the top of the form and shrink away above this level.

PLATE 105.—Contract 12. Grouting Outfit as Used in Rondout Tunnel. Worthington High-stage Compressor (350 lbs.) and Caniff Grouting Machine Mounted on Movable Platform. Valve on grout pipe is operated by men on platform. Grouting was mostly done by direct air pressures of 40 to 100 lbs. per square inch. Remainder with high air up to 350 lbs. per square inch.

Trouble Caused by Leaky Joints. It was found difficult to hold the grout under pressure above the arch because the transverse joints above springing line, which occur about every 45 feet, opened slightly and leaked considerably when placed under pressure. The opening at the joints is explained by the decrease in temperature from the time of setting, about 100°, to the time of placing grout, about 50°. The grout was usually 1 cement to 1 very fine sand by volume, the sand being of great aid in plugging joints, and preventing the undue running of the grout. However, even a 1 to 1 grout seemed to run freely for hundreds of feet when first placed, so that almost any pipe leading to the top of the arch could be used for grouting, and no sharp distinction between grout and vent pipes was necessary.

Grouting between Shafts 5 and 6. Great care was used in grouting the stretch between Shafts Nos. 5 and 6. The work was gone over several times until finally there remained no spaces to be filled with grout. Some of the high pipes were opened up repeatedly and regrouted. The vertical joints in the wet stretches, despite every effort, still leaked slightly. Holes were drilled into the joints, grout pipes placed and attempts made to fill them with grout. This proved ineffective, as water circulating through the joint would gradually wash out the grout, starting up the old leak. In fact, it is extremely difficult to stop any leak which comes through the body of the concrete by grouting, as the grout which may reach the porous concrete, crack or joint responsible for the leak is carried to the face of the concrete by the water.

Grout Pads. Grout pads as required by the contract were furnished and tried. These consist of a column, similar to that used for mounting drills, at the end of which is a casting containing a rectangular rubber gasket. The pad, 15″×20″ about 3″ deep, is jacked against the leaky spot by means of screw-jacks at the other end of the column, after which grout is pumped into the pad, and allowed to set, the theory being that the grout will penetrate the porous concrete, stopping off the leak. It was, however, found that the area covered is too small for effective work and the pads with columns, etc., very clumsy to handle. Its utility at any rate was small. In very few cases did any grout leak through the body of the concrete, this being in places where dry concrete was inadvertently used. None of the sections placed with wet, dense concrete was penetrated by the water.

Grouting between Shafts 7 and 8. In the next stretch grouted between Shafts 7 and 8, advantage was taken of the experience gained between Shafts 5 and 6, and a simple method of grouting adopted. Machines were started at Shaft No. 7 and the grout driven ahead, air pressure of 50 pounds to the square inch being used. No attention was paid to cut-off walls, the grout being pumped continuously into a pipe until it appeared about 150 feet ahead, when the grout plant was moved this distance and a new connection made. The isolated pipes below the top of the waterway were plugged with grout, pressures up to 250 pounds being used. A few of the high pipes in the arch were opened and grouted at high pressure, but these took comparatively little grout. This grouting was aided by the 2 per cent incline up which the grouting was done. Rapid progress was made by this method and the results obtained appeared to be very good.

Grouting Wet Stretch North of Shaft 4. Perhaps the most interesting work of grouting was that performed in the very wet stretch of ground on the incline north of Shaft 4. As described before, the inflow into 350 feet of tunnel was 1950 gallons per minute (Dec. 1, 1910), which gradually diminished to 1000 gallons per minute at the time of grouting (Jan. 27, 1912). The rock along the stretch was porous and much broken up by folding and faulting. The wettest stretch of 175 feet was protected by a steel shell (Plate 94). The concrete in the invert was placed, first, in stretches of 25 to 40 feet, most of the water being diverted through 6-inch branches into the 8 inch-spiral riveted main drain. Water which got between the invert forms through seams or springs was dammed off by sandbags and diverted into a hole in the top of the subdrain. Over a portion of the bottom it was necessary to lay stone drains. The 2-foot concrete lining was readily placed inside the steel shell, which effectively shed the water, very little dripping through the plate joints.

Cut-off walls were built over the arch at each end of the wet stretch; they were composed of four brick walls built tight against the roof and the space between them grouted. The tunnel both above and below the very wet stretch was thoroughly grouted in the usual way, as it was deemed advisable to force all the water into the stretch covered by steel lining where special provisions had been made for handling it.

Grout Pipes. Two systems of grout pipes were placed, one to reach the dry packed space back of the steel lining; the other, known as deep-seated pipes, was inserted, previously to the placing of the steel, into all flowing seams to depths of 3 to 4 feet.

Grouting behind Steel Shell. Before grouting the dry packing the 8-inch drain at the bottom was closed by a valve, and a few pipes left open to prevent accumulation of head. This formed a pond of still water into which neat cement grout was placed, as experiments previously made showed that grout of sand and cement was liable to stratify when forced into a confined space containing water. A battery of four Caniff machines mounted on a car was used, grouting proceeding from the lower end. As the grout rose, it could be followed by opening pipes at various levels. The deep-seated pipes were allowed to flow so as to reduce the pressure while the dry packing was being grouted; however, a few which showed grout were promptly closed, but later opened after the grout had set. The final grouting of dry packing was done at a pressure of 90 pounds at the top of the incline. The machines forced in 7693 batches of neat grout (1.2 cu.ft. each) in 10 shifts, the maximum quantity for any one shift being 1207 batches, this being the record for any tunnel on the line.

Grouting Deep-seated Pipes. After the grout had set a few days the deep-seated pipes, through which a few hundred gallons of water issued per minute, were grouted with a thin grout, each taking from a few batches to 531 batches under a pressure of 300 pounds.

Reduction of Leakage through Grouting. The leakage on the incline was reduced from 1000 gallons per minute to 8 gallons, and the grouting was thus extremely satisfactory and successful. The inflow through the lining has increased only slightly, although the head on the tunnel increased from 58 feet upon the completion of the grouting to 106 feet ten days later and increased, as shown on Plate 106. The size of the rock reservoir adjacent to Shaft 4 is indicated by the absorption of over 1000 gallons of water per minute for forty days, while the rock water level was rising from elevation −185 to elevation −65, the latter being the elevation of the pump chamber. Pumps were placed in the chamber to enable the shaft plug to be placed.

The results achieved at Shaft 4 were due to the great care in providing for the free passage of water while concreting, and to the placing of the pipes so as to enable the lining to be surrounded by a layer of grout, which effectively sealed off the water.

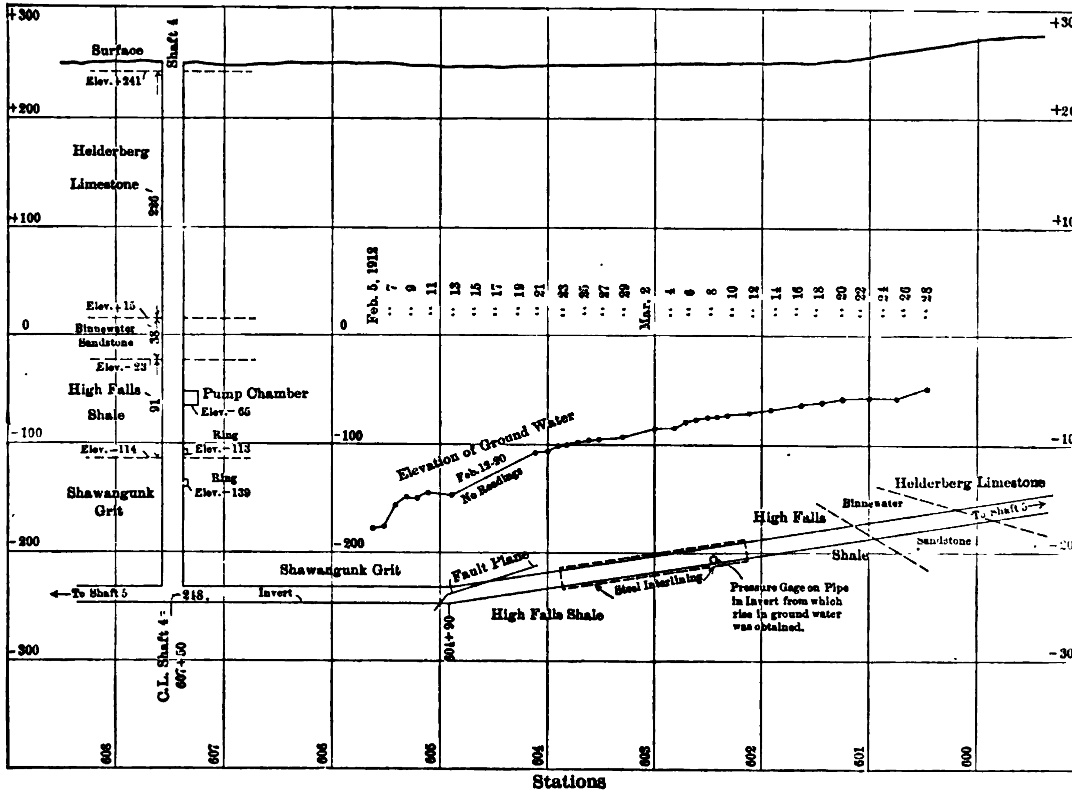


PLATE 106.—Profile of Rondout Pressure Tunnel Adjacent to Shaft 4, Showing Stratification and Fault in Wet Ground and Rise in Ground Water Level after Grouting Off Flow of 1000 Gallons per Minute at Steel Interlining. Wet strata were the Binnewater sandstone and High Falls shale. Tunnel was very wet near fault plane.

MATERIALS USED IN GROUTING RONDOUT PRESSURE TUNNEL

Between Shafts.	Distance, Feet.	Barrels Cement Used.	Sand Used, Tons.	Barrels Cement per Foot.	Pounds Sand per Foot.	Remarks.
1–2	3900	2712	323	0.695	166	Only 4 cu.yds. dry packing used.
2–3	4400	2528	322	0.576	146	Only 10 cu.yds. dry packing used.
3–4	4050	9649	856	2.380	423	Includes vertical cavities in roof and dry packing behind steel lining.
4–5	2750	2539	323	0.921	235	Includes 168 cu.yds. dry packing.
5–6	3200	2607	327	0.816	204	Includes 391 cu.yds. dry packing.
6–7	3200	2103	272	0.666	170	Includes 119 cu.yds. dry packing.
7–8	2000	947	125	0.473	125	No dry packing; 2 per cent grade.

General Conclusions as to Grouting. The grouting of a tunnel being a process performed more or less in the dark, is not one for which an exact procedure can be laid down in advance. It is found that equally good men will grout with quite different methods, but the results will be about equal. It is an operation requiring a great deal of patience and persistence and repeated going over of same work. Where there are many pipes placed, the exact order in which they are connected is not a matter of great importance, though in general it is better to connect with the shorter pipes in the arch, using the high ones as telltales, and vents for the escape of air and water. In some of the later concreting, special effort was made to obtain tight joints in wet sections. In each arch joint two or more grout pipes were placed, and in some cases grouting grooves were formed. Although with these devices grout could freely be forced into the joints, still when grouting ceased water would slowly circulate through the joint, opening up new channels, resulting in the restoration of the old leaks. Steel plates were used in some other cases in the arch joint, the purpose being to provide a stop for the grout, which after setting would permanently tighten the joint. This has proven to furnish the best joint for wet sections.

Considerable success has been recently attained in closing leaky expansion joints by hand calking. A deep groove is cut in the joint and $\frac{1}{4}$-inch lead wire hammered in. This is inexpensive and apparently permanent. Joints have been successfully calked against an outside pressure of over 130 pounds per square inch.

Final Leakage into and out of Lined Tunnel. It is to be noted that leaks through the joints as described is an inward leakage due to the surrounding ground water, and has no necessary relation to outward leakage when the tunnel is in service. Further, these inward leaks, though very conspicuous, amount to very little in gallons per minute. For the water to escape it would be necessary to penetrate hundreds of feet of rock after passing the tunnel lining. The grouting is indispensable and invaluable for this class of work, as it fills up the voids back of the tunnel lining, so that the internal pressure is transmitted to the rock, and moreover prevents the water from circulating over the arch and reaching porous places in the rock. Originally it was hoped that by the use of high grouting pressures the rock in contact with the lining could be thoroughly impregnated with grout so as to make it waterproof independently of the concrete lining. However, it was not found that high grouting pressures could be used to much advantage. The process of grouting is really a gradual silting up of the spaces surrounding the arch and plugging up of springs leading to the vent pipes. It is not probable that the grout will prevent the ground water from reaching the concrete lining which after all must be the main reliance in keeping the water out when the tunnel is empty or in when in service. For this reason the concrete arch should be reasonably thick so that the men can conveniently work behind the forms. Ten or twelve inches of rich dense concrete placed very wet and rammed in level layers with all spaces behind grouted will prove very tight. Considering that this tunnel is hundreds of feet below ground water and without waterproofing, the dryness of the concrete is remarkable.

Sealing Construction Shafts. The construction shafts were sealed against future outward leakage from the tunnel when in service by removing the lower 75 feet of timbering and placing a concrete plug in which were inserted three grout pans about 6 feet, 13 feet, and 31 feet from top of waterway. These pans were 2 feet wide and continuously united around the shaft. They were placed against the rock sides and the lower edge was sunk 6 inches into set concrete, the upper edge being caulked with oakum and cement. Two grout pipes led upward to the top of the plug and one, a vent or drain pipe, to the waterway below. The pans were cleaned with air and water, and neat grout forced in at 300 pounds pressure, using a Caniff machine and Westinghouse booster. At Shaft 6, the lower pan took 76 cubic feet of grout, the middle pan 54, and the upper pan 64 cubic feet, some of the grout, which was forced under heavy pressure to the top of the plug, appearing along the sides in seams which, however, soon plugged themselves. The water entering the shaft above the plug was collected in a ring about 75 feet above the waterway and led through a pipe to the tunnel.

Leakage through Plug at Shaft 7. The efficiency of the shaft plugs was well demonstrated by a test at Shaft 7. The inflow into this shaft was about 65 gallons per minute, which, when the drain pipe through the plug was closed after grouting, rapidly accumulated above in the shaft to ground-water level, a depth of 419 feet, as indicated by 182 pounds pressure on a gauge in the drain pipe at the foot of the shaft. This pressure increased the leakage into a stretch of 660 feet of tunnel each side of the shaft from 2 gallons per minute to 9 gallons per minute, an increase of only 7 gallons. The increased leakage appeared mainly at two transverse points near the shaft. This is considered a very creditable showing.

Concreting Bonticou Grade Tunnel. Bonticou tunnel was the first grade tunnel concreted, and the standard practice and forms were here developed. As in the case of the pressure tunnel, Blaw forms were used, and they were delivered without carriages, the intention being to take the forms apart and carry them forward by hand and set them up. This was found impracticable and a wooden carriage with jacks, such as used for the bottom forms, in the pressure tunnel, was fitted to 30 feet lengths and the forms made collapsible by cutting the braces at the springing line and equipping them with turnbuckles. By unbolting the ribs at the top they could be collapsed and the forms lowered and sprung in by the turnbuckles, clearing the concrete sufficiently to allow the form to be moved forward on the wide-gauge track provided. As the grade-tunnel section is high and narrow, side walls and arch are concreted in one operation, with all except a few of the top plates left permanently in place.

The concrete was hauled in side-dumping cars by mules from a mixing plant at the portal and raised by a cable to the platform at the springing line up an incline similar to that used in pressure tunnels; the concrete after being dumped was then shoveled behind the forms, the men in them spading and leveling. Above the springing line the concrete was cast in place by hand. To reach the key a higher temporary platform was used. The keying proceeds from the end nearest the finished concrete, $2\frac{1}{2}$-foot key-plates being gradually added. Three sets of 30-foot forms were used, the forms allowing the concrete cars to pass through. A form was usually made ready and filled every day, as usual the slow part of the work being the keying. Several changes had to be made toward strengthening and improving the forms used. Nevertheless good progress was made, 3340 feet of side wall and arch being concreted in six months, the maximum

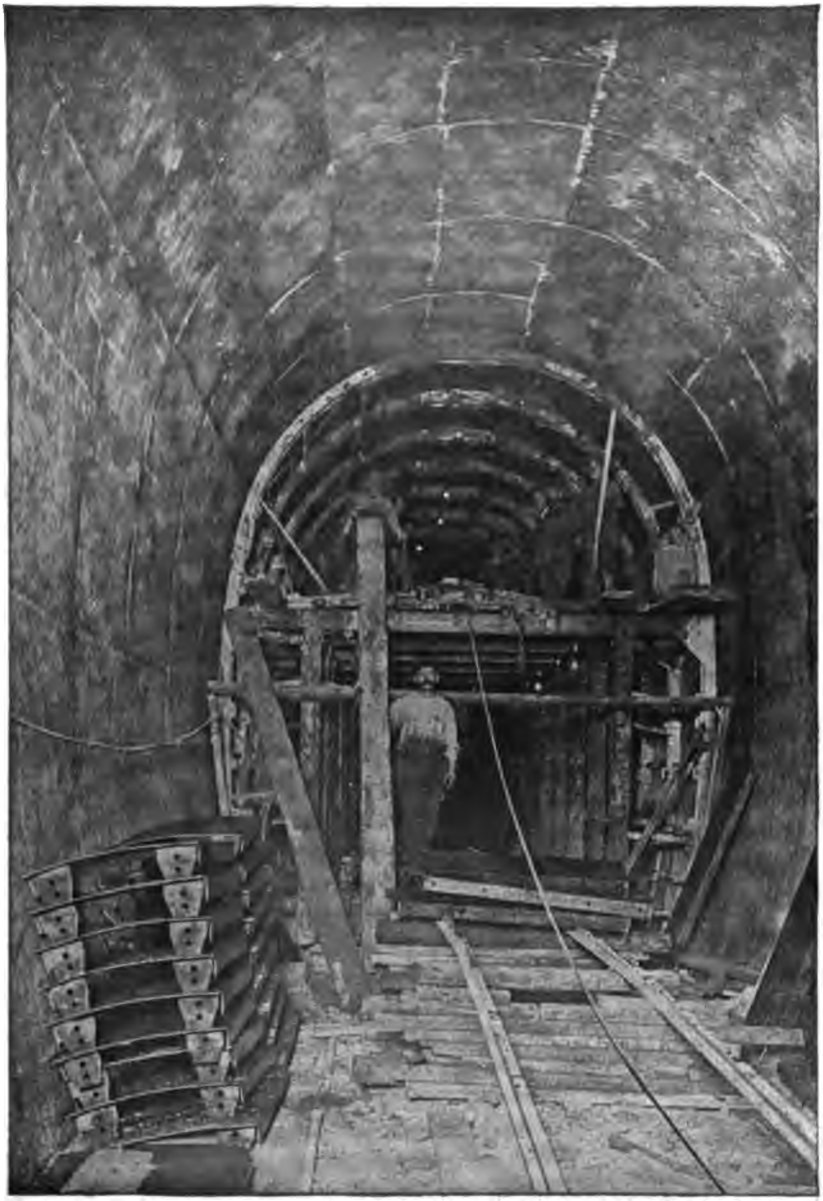


PLATE 107.—Contract 12. Blaw Grade Tunnel Forms. Form was filled in 30-foot lengths and collapsed by pulling in sides at mid-diameter with turnbuckles, unbolting ribs at center and lowering with jacks on wooden carriage running on rails. See also Plate 113.

monthly progress being 766 feet. To provide foundation for the forms, narrow footing courses, 9 inches thick by 2 feet wide, were laid to proper grade each side of the tunnel. These proved to be of great assistance in setting forms.

Concreting of Invert. The arched invert was laid last, only about 5 inches thick, being provided with a box drain, frequent openings being made through the invert to prevent pressure from accumulating on it when the aqueduct is not in service. The invert was rapidly laid at the rate of 100 feet a day, profile boards being wedged in against the side walls and used to serve as guides for the long screeds used for shaping invert.

Placing of Weepers and Drip Pans. In concreting the grade tunnels, the pipes were used as weepers to prevent water from percolating through the concrete while green, wet areas being also protected by drip pans as previously described in the pressure tunnels. To prevent ground water from accumulating upon the arch, pipes were concreted in with the key. No effort was made to secure tight joints, as the inward leakage into the grade tunnel can do no harm. A short section of tunnel was grouted near the portal and the sub-drain plugged to prevent outward leakage around the tunnel lining.

Hydrostatic Test of Rondout Siphon. The contract provides for a hydrostatic test for the whole of the Rondout siphon. Three months after the concrete lining is all placed and grouted, the tunnel is to be filled with water to hydraulic grade. From the terminal shafts observations can then be readily made. At the drainage shaft, No. 5, a centrifugal electrically operated pumping plant is to be provided under another contract. The pumps are to be mounted on a cylindrical steel float which will descend in the shaft as fast as the water is lowered by pumping, a length of discharge pipe being added at the same rate. This plant on reaching the bottom will pump out the entire siphon at the rate of 3000 gallons per minute. An examination is then to be made of the tunnel to see how it withstands the internal pressure and any defects repaired, after which the tunnel will again be filled, and the leakage noted, and if thought necessary again pumped out for re-examination.

PLATE 108.—Completed Pressure Tunnel Lining. Note smooth finish and close joints at invert and springing line. Concrete surface very dry under high ground water bend.

CHAPTER IX

WALLKILL PRESSURE TUNNEL, NORTH CUT-AND-COVER, AND ONE-HALF BONTICOU TUNNEL

General Description Contract 47. Contract 47, one of the major aqueduct contracts, comprising about 9 miles of aqueduct of various types and 2323 feet of shaft, was awarded March 27, 1909, to the Degnon Contracting Company, for a total of $4,982,726. It includes the southern half of Bonticou tunnel, about 4 miles of cut-and-cover and 560 feet of the Mohonk tunnel between it and the Wallkill pressure tunnel. The cut-and-cover follows along the slope at about 470 feet contour, with an average cut of about 13 feet. The pressure tunnel crosses beneath the Wallkill River at a depth of from 350 to 480 feet, and was constructed from six shafts, three of which are permanent.

Contract Prices. The contract quantities and items are given in the table, pages 334 to 337.

Linear Foot Costs. On the basis of the contract quantities and prices the following unit costs to the city have been compiled.

20,000 lin.ft. cut-and-cover aqueduct at $59.58 per foot; 4010 ft. grade tunnel at $92.01 per foot; 23,390 ft. pressure tunnel, including shafts and drainage drifts, at $146.31 per foot.

The pressure tunnels cost per foot is subdivided as follows:

Construction Shaft.		Waterway Shaft.		Drainage Shaft.		Tunnel.
Earth.	Rock.	Earth.	Rock.	Earth.	Rock.	
$258.70	$278.69	$316.84	$238.42	$329.87	$253.05	$114.59

Pumping Item. There is an item for pumping, the bid price being 15 cents per million foot-gallons, but no direct payment is made for pumping plant as on the Rondout siphon. On this contract but small quantities of water were met and, as anticipated, the expenditure for pumping plant was small.

Character of Rock in Tunnel. Borings made previously to the letting of the contract indicated that the rock to be penetrated by the pressure tunnel would probably be sound and dry, and as it was entirely of one character good progress was to be expected. Very economical and efficient work was necessary to keep the cost materially below contract prices. In this region there was encountered but one rock formation, known as the Hudson River shale, composed generally of a rather hard black shale with some included beds of hard sandstone and of soft shale. The earth is mainly a hard glacial drift.

The Bonticou tunnel and adjacent portion of the cut-and-cover (15,000 feet) was supervised by Carpenter & Boxley, and the portion north of Shaft 1 (8600 feet) by James Pilkington. The sinking of the shafts was done by the Dravo Contracting Company.

Bonticou Tunnel. Carpenter & Boxley established a compressor plant at the point on the Wallkill Valley R. R. nearest the Bonticou tunnel. Here a steam plant operated two compressors with a combined capacity of 1900 cubic feet of free air per minute. An air line was laid from the plant to the portal of the Bonticou tunnel and to an adjacent deep rock cut.

The first 606 feet of the tunnel proved to be in rock requiring permanent timber support, the next 55 feet temporary support, after which the rock was such as to require no support and permitted a very good progress. The average progress was about 265 feet a month for thirteen months, and the maximum monthly progress 338 feet (May, 1910); during 1910, the average progress was 285 feet per month, somewhat less than made in the northern half of the tunnel under Contract 12. The tunnel was driven by the usual top heading and bench method (Ingersoll-Rand reciprocating drills being used) and the muck was hauled out by narrow-gauge cars and dumped on the spoil bank. The heading was drilled for 24 holes fired in four rounds and loaded with 60 per cent dynamite. About 5¾ pounds of powder per cubic yard per advance of 7½ feet was used in the heading as against ¾ pounds per cubic yard for the bench.

Freer Cut. About one-half mile from the Bonticou south portal is a cut in rock known as the "Freer Cut." This cut is about 2000 feet long with a maximum depth of about 49 feet and an average depth of 40 feet. The excavation was made with a steam shovel in the usual way, loading cars on a track alongside the shovel. It was found that the slaty rock in the uphill slopes had a strong tendency to slide into the cut, for the reason that the layers of hard shale dipping about 45° were separated by smooth bedding planes, so that when the rock was undercut immense slabs 1½ inches to 24 inches thick slid toward the excavation. After exposure the layers

BOARD OF WATER SUPPLY OF THE CITY OF NEW YORK

CONTRACT 47, WALLKILL PRESSURE TUNNEL OF THE CATSKILL AQUEDUCT

(Canvass of Bids opened March 18, 1909)

THE DEGNON CONTRACTING CO., 60 WALL STREET, NEW YORK CITY.

Item.	Description.	Unit.	Quantity.	Price.	Amount.
1	Construction shafts in earth	Linear foot	130	250.00	32,500.00
2	" " in rock	"	930	275.00	261,250.00
3	Refilling construction shafts	"	130	5.00	650.00
4	Waterway and drainage shafts in earth	"	105	250.00	26,250.00
5	Rock excavation in waterway and drainage shafts	Cubic yard	13,000	15.00	195,000.00
6	Excavation of pressure tunnel and drainage drift	"	253,000	6.00	1,518,000.00
7	Additional trimming in shafts, pressure tunnel and drainage drift	Square yard	500	4.00	2,000.00
8	Furnishing structural steel roof support	Pound	1,220,000	.03	36,600.00
9	Erecting structural steel roof support	"	1,220,000	.01	12,200.00
10	Temporary timbering in pressure tunnel and drainage drift	M ft. B. M.	125	60.00	7,500.00
11	Pumping from shafts and pressure tunnel during construction	Mil. ft. gals.	400,000	.15	60,000.00
12	Drainage channels for shafts and pressure tunnel	Lin. ft. of tunnel	25,750	1.50	38,625.00
13	Forms for lining of waterway shafts and outer lining of drainage shaft	Lin. ft. of shaft	1,220	6.00	7,320.00
14	" inner lining of drainage shaft	" "	360	5.00	1,800.00
15	" " lining of pressure tunnel and drainage drifts	Lin. ft. of tun. and dr.	23,470	3.00	70,410.00
16	Concrete masonry in shafts	Cubic yard	7,800	7.00	54,600.00
17	" in pressure tunnel and drainage drift	"	100,000	6.00	600,000.00
18	Excess concrete masonry in shafts, pressure tunnel and drainage drift	"	5,000	3.00	15,000.00
19	Brick masonry in shafts, pressure tunnel and drainage drift	"	200	20.00	4,000.00
20	Dry packing in pressure tunnel	"	7,000	2.50	17,500.00

21	Drainage interlining in drainage shaft	Square foot	17,500	.15	2.625.00
22	Furnishing and erecting steel castings and special valves	Pound	7,500	10	750.00
23	Bronze access door and frame	"	8,500	60	5,100.00
24	Structural steel interlining in drainage drift and pressure tunnel	Pound	60,000	.06	3,600.00
25	Cutting channels for water stops	Square fcot	450	1.25	562.50
26	Lead-lined, 16-inch, cast-iron pipe and specials	Linear foot	415	24.00	9,960.00
27	Drilling 1½-inch or smaller holes in rock or masonry	"	2,500	.50	1,250.00
28	" 1¾ to 2½-inch holes in rock or masonry	"	2,500	.60	1,500.00
29	Steel pipe for grouting, etc., in shafts, pressure tunnel and drainage dr.	"	40,000	.20	8,000.00
30	Miscellaneous plant and equipment for grouting in pressure tunnel, etc.	Lump sum	....	....	5,000.00
31	High-pressure air-compressors for grouting	Compressor	10	300.00	3,000.00
32	Tank-grouting machines	Machine	10	250.00	2,500.00
33	Grouting pads	Pad	50	60.00	3,000.00
34	Making connections of tank-grouting machines to grout pipes, in shafts, etc.	Connection	7,000	.60	4,200.00
35	Setting grouting pads in pressure tunnel and drainage drift	Setting	2,000	1.00	2,000.00
36	Sand for grout in shafts, pressure tunnel and drainage drift	Ton	3,700	1.50	5,550.00
37	Mixing and placing grout in shafts, pressure tunnel and drainage drift	Cubic yard	5,000	4.00	20,000.00
38	Hydrostatic tests of pressure tunnel	Test	2	3,000	6,000.00
39	Removal of top-soil	Cubic yard	79,000	.40	31,600.00
40	Open-cut excavation Sta. 788+50 to Sta. 814	"	28,000	.90	25,200.00
41	" " " 814 to Sta. 834	"	85,000	1.20	102,000.00
42	" " " 834 to Sta. 865	"	33,000	1.10	36,300.00
43	" " " 865 to Sta. 905+10	"	61,000	.70	42,700.00
44	" " " 910+70 to Sta. 990	"	120,000	.60	72,000.00
45	" " " 990 to Sta. 1108	"	10,800	.70	7,560.00
46	" " " 1108 to Sta. 1228	"	3,600	.70	2,520.00
47	Refilling and embanking, Sta. 788+50 to Sta. 814	"	50,000	.30	15,000.00
48	" " " 814 to Sta. 834	"	12,000	.30	3,600.00
49	" " " 834 to Sta. 865	"	37,000	.30	11,100.00
50	" " " 865 to Sta. 905+10	"	60,000	.30	18,000 00
51	Refilling and embanking, Sta. 910+70 to 990+00	Cubic yard	104,000	.30	31,200.00

BOARD OF WATER SUPPLY OF THE CITY OF NEW YORK—*Continued*

Item.	Description.	Unit.	Quantity.	Price.	Amount.
52	Refilling and embanking, Sta. 990 to Sta. 1108	Cubic yard	14,000	.30	4,200.00
53	" " " 1108 to Sta. 1228	"	11,000	.30	3,300.00
54	Surface dressing and grassing	"	59,000	.60	35,400.00
55	Concrete masonry for aqueduct in open cut and on embankment	"	94,400	5.50	519,200.00
56	" " culverts, chambers, etc	"	6,100	6.00	36,600.00
57	Reinforced concrete not in tunnels	"	300	8.00	2,400.00
58	Stone masonry facing	"	250	15.00	3,750.00
59	Dry rubble masonry and paving	"	2,975	2.50	7,437.50
60	Rubble masonry and paving in mortar	"	100	3.50	350.00
61	Surfacing permanent access roads	"	1,750	2.00	3,500.00
62	Crushed stone and gravel	"	400	1.50	600.00
63	Sluice gates	Gate	7	90.00	630.00
64	Cast-iron pipe and special pipe castings	Ton	24	75.00	1,800.00
65	Vitrified pipe	M feet	1,500	1.00	1,500.00
66	Timber and lumber	M feet B.M.	140	60.00	8,400.00
67	Testing portions of aqueduct	Portion	9	500.00	4,500.00
68	" " aqueduct exceeding 200 feet in length	Lin. ft.of excess	1,150	1.00	1,150.00
69	Rock excavation in grade tunnels	Cubic yard	45,500	5.00	227,500.00
70	Additional trimming in grade tunnels in rock	Square yard	500	1.50	750.00
71	Earth excavation in grade tunnels	Cubic yard	100	6.00	600.00
72	Enlargement of grade tunnel section in earth	"	100	8.00	800.00
73	Permanent timbering in grade tunnels	M. feet B.M.	125	60.00	7,500.00
74	Temporary timbering in grade tunnels	"	50	60.00	3,000.00
75	Grade tunnel drainage	Lin. ft. of tun.	4,010	.50	2,005.00
76	Forms for masonry lining in grade tunnels	"	4,010	2.50	10,025.00

77	Concrete masonry in grade tunnels	Cubic yard	12,100	5.50	66,550.00
78	Excess concrete masonry in grade tunnels	"	800	2.50	2,000.00
79	Brick masonry in grade tunnels	"	200	10.00	2,000.00
80	Dry packing in grade tunnels	"	2,500	2.50	6,250.00
81	Drilling holes in rock or masonry in grade tunnels	Lin. foot	400	.50	200.00
82	Steel pipe for grouting in grade tunnels	"	1,500	.25	375.00
83	Portland cement	Barrel	342,000	1.45	495,590.00
84	Grout of Portland cement in grade tunnels and aqueduct in open cut and on embankment	Cubic yard	850	4.00	3,400.00
85	Sulphate of alumina for waterproofing concrete, mortar or grout	Pound	250,000	.02	5,000.00
86	Stone boundary walls	Lin. foot	46,000	.70	32,200.00
87	Fences and guard rails	"	14,800	.25	3,700.00
88	Steel for reinforcing concrete	Pound	186,000	.04	7,440.00
89	Miscellaneous cast iron, wrought iron, and steel	"	7,100	.06	426.00
90	Galvanizing	"	5,000	.05	250.00
91	Bronze pipe and miscellaneous bronze	"	8,900	.55	4,895.00
92	Reinforced concrete ladders	Lin. foot	80	2.00	160.00
93	Moving "Smiley" house	Lump sum	....	1500.00	1,500.00
94	" "Du Bois" house	"	....	1500.00	1,500.00
95	Locker houses	House	5	1500.00	7,500.00
96	Cleaning up	Lump sum	....	10000.00	10,000.00
	Amount of bid				$4,982,726.00

Time: 49 months. Bond required, $800,000. Engineer's estimate, $5,979,043.

PLATE 109.—Contract 47. Excavation of Freer Cut in Sliding Hudson River Shale. Slope on right was very troublesome, large slabs breaking off and sliding, on "slickensided," planes into cut.

up to 500 cubic yards would crumble and slide toward the cut at unexpected times and endanger steam shovel and drills. The rock on the downhill slopes stood up very well, the tendency there being for the layers to support themselves. It was found advisable to throw the center line of the cut further east and to allow flat slopes on the west side in order not to again undercut the beds on that side, which would probably cause heavy slides with danger to life and property, and to build the aqueduct with a wide base instead of the usual rock section.

Excavation and Concreting. For ordinary cuts a long-boom 60-ton shovel was used with lift of 26 feet and reach of 40 feet. The excavation was spoiled on the downhill side of the trench and used for grading a 36-inch-gauge track, or loaded upon side-dump cars hauled by dinkies, to fill in the low spots for tracks or carried to spoil banks.

The aqueduct was concreted with the usual equipment of stationary mixing plant, locomotive crane, and Blaw forms. A simple concreting plant was installed which proved to be very efficient. The stone and sand was supplied from the main contractor's railroad, the cars dumping directly into bins built on the uphill slope of the cut. A 31-cubic foot Smith rotary mixer discharged into Lockwood automatic bottom-dumping buckets hauled in trains of four flat cars to the work, where they were dumped over the forms by an Industrial locomotive crane with a 45-foot boom. The crane was supplied with a double hook attached to two lines on its drum (see Plate 112). The concreting was kept from 150 to 1500 feet from the shovel, and the invert 15 feet to 900 feet ahead of the arch. Four buckets were carried on two flat cars and a maximum haul of 6800 feet was made in fifteen minutes.

Usually 60 feet of arch were concreted daily. With this plant, 75 feet of arch were concreted in 5½ hours, but the usual progress was 60 feet per day, as it is not practicable to get ready such a length of form each day. The maximum monthly work in 1911 was 985 linear feet, and the average progress 785 feet. Concreting was not done every day.

Concreting in Freer Cut. The concreting of the aqueduct in the Freer cut had to be done from one end, as no tracks could be laid at the side. This delayed progress somewhat, so that only 45 feet of arch could be concreted every other day. It was necessary to carry the concrete on a track on the completed invert and place the buckets ahead by the locomotive crane, which was elevated

PLATE 110.—Contract 47. Carpenter and Boxley Side Hill Concreting Plant for Cut-and-cover Aqueduct. A very simple and economical plant.

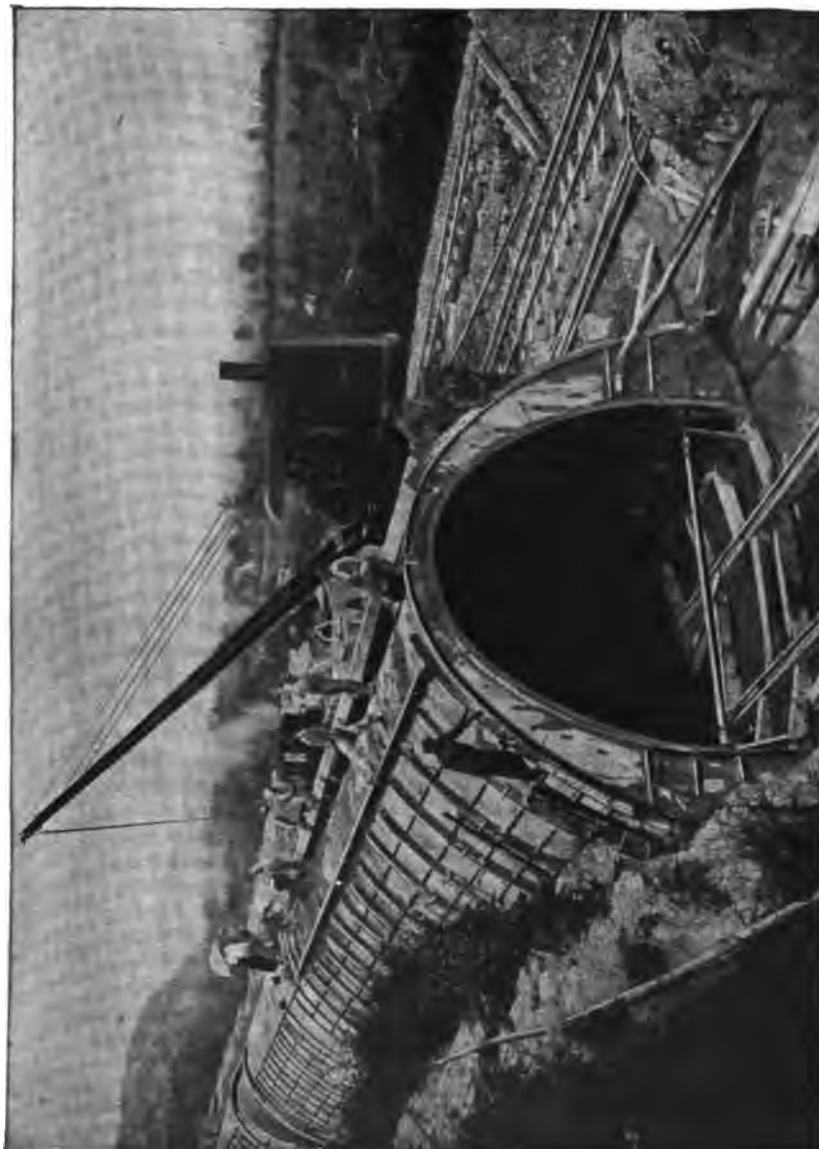


PLATE 111.—Contract 47. Carpenter and Boxley Concreting Arch for Cut-and-cover Aqueduct. 75 feet—about 300 yards—were placed in 8 hours by the locomotive crane. Concrete hauled in "Lockwood" buckets from plant shown on Plate 110.

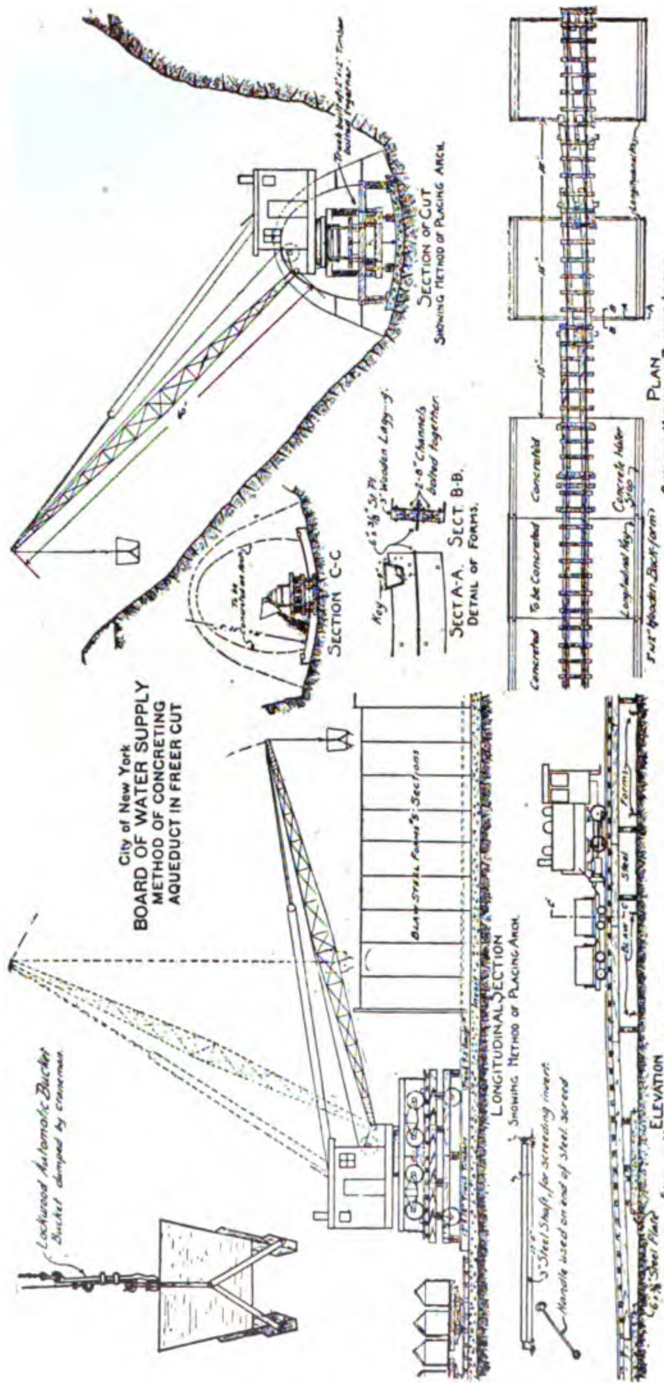


PLATE 112.—Contract 47. Method of Building Cut-and-cover Aqueduct in Deep "Freer Cut," Using Locomotive Crane on Moving Platform. Automatic buckets, etc. Very successful for cut where no tracks could be laid alongside on bank.

above the invert on a trestle, so as to reach the front end of the form. (See Plate 112.)

Concreting Bonticou Tunnel South. Blaw forms similar to those used in Contract 12 were installed in Bonticou tunnel south, one set of 30 feet at the end and two others of 30 feet at each third point. No difficulty was experienced in filling a 30-foot section with concrete in about fourteen hours, 117 30-foot sections being concreted in 120 working days (about 10,290 cubic yards). The force was disposed as follows:

8 A.M. to 4 P.M. Concreting at forms, 13 men; moving forms, 13 men; at mixer, 7 men.

4 P.M. to 12 P.M. In tunnel, 13 men; at mixer, 7 men.

12 P.M. to 8 A.M. Sealing rock and miscellaneous work, 10 men.

Invert Concreting. The invert was concreted one-half at a time with a longitudinal joint on the center line. Forty cubic foot side-dump Koppel cars were loaded at the portal from a mixer set overhead, discharging through 45 feet of 10-inch pipe. The cars dumped directly into the forms. About 600 feet on one side was concreted, after which the track was thrown onto the finished invert and the other half concreted. From 300 feet to 655 feet of one-half invert was concreted in one eight-hour day (30 to 65 cubic yards). The bottom drain was left open and connected with 2-inch pipes, at 200 feet intervals, through the invert to prevent upward pressure on the light 5-inch bottom.

Work South of Mohonk Tunnel. On this section of cut-and-cover a plant entirely different from any other on the line of the aqueduct was installed. Mr. Pilkington, the superintendent, previously had wide experience in constructing sewers in cities, and endeavored to build this part of the aqueduct in a similar manner. A trestle about 750 feet long was erected of $12'' \times 12''$ timber bents spaced 15 feet on centers, spanning the trench and carrying a system of four travelers, three equipped with a derrick and hoisting engine, and one traveler carrying in addition a concrete mixer. The function of the first traveler was to build the trestle in advance as fast as the fourth traveler took it up in the rear, and send the timber ahead on the dinky track paralleling the trench. The second mucked out the trench bottom and handled the concrete forms. The third lifted the dry concrete in skips from dinky cars on the track alongside, mixed the concrete and discharged it directly into the forms. The fourth traveler handled the outside forms from the completed aqueduct, placed the refill with an orange-peel bucket, and finally took down the trestle. Derricks and steam shovels were used for the excavation. It

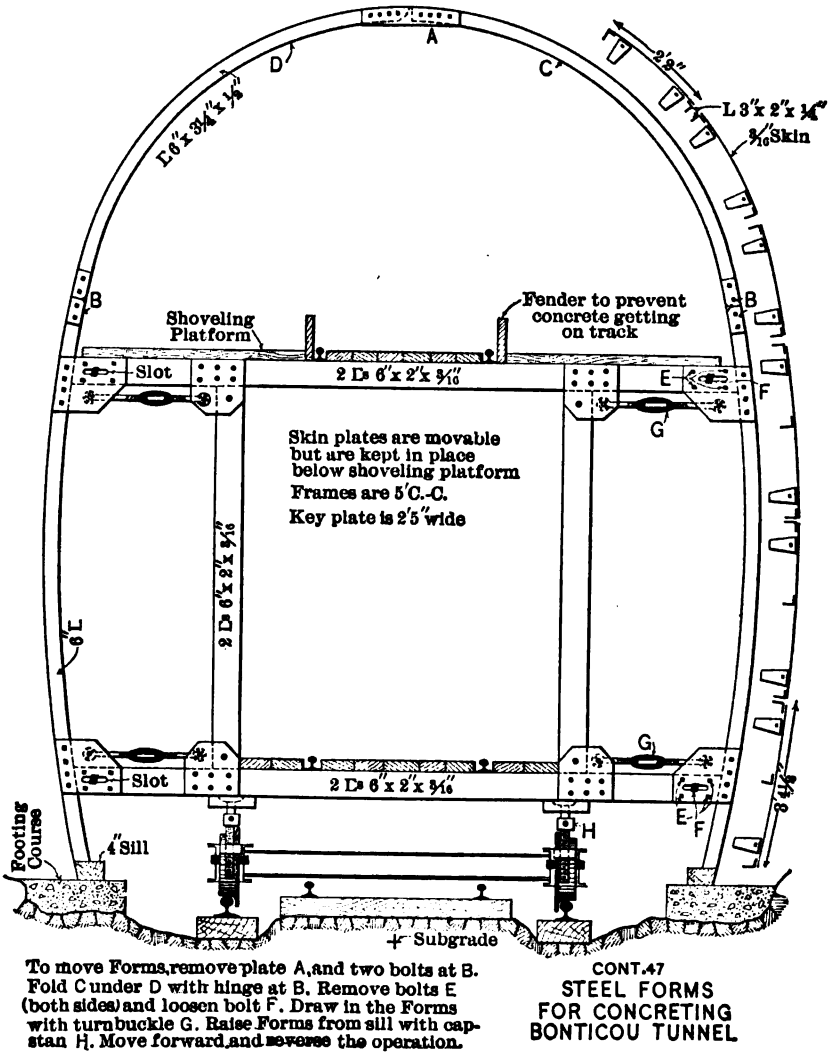
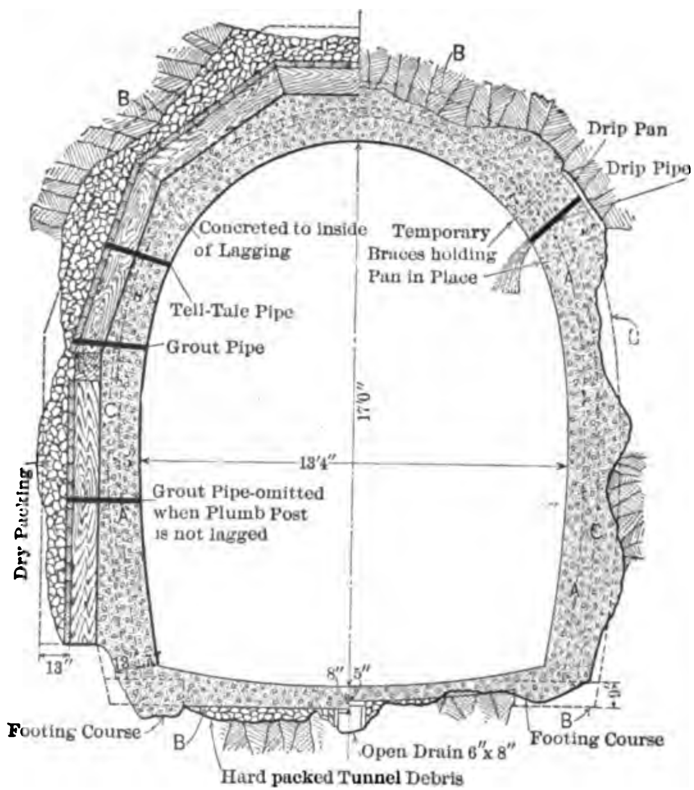
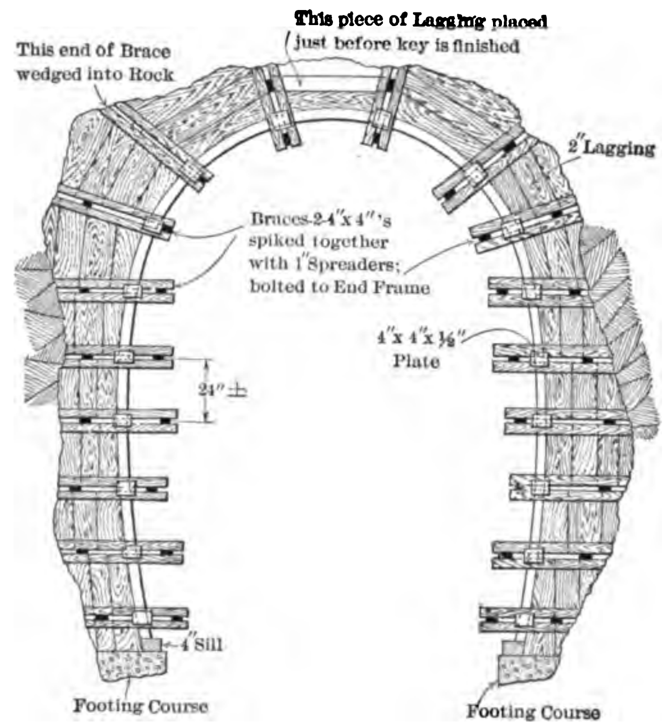


Plate 113.—Contract 47. Details of and Method of Moving Blaw Steel Grade Tunnel Forms for Bonticou Tunnel South.



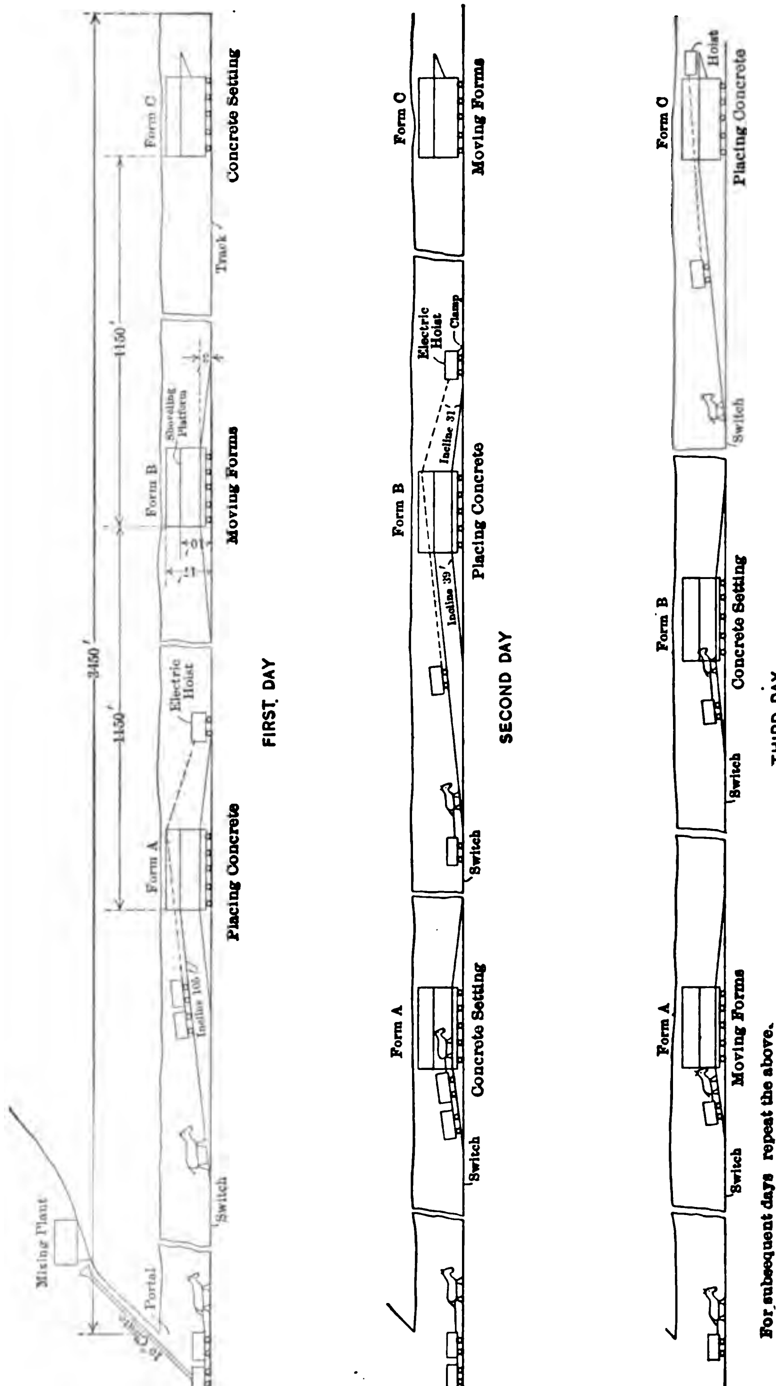
TYPE B-TIMBERED ROCK
SHOWING
A, B, C, LINES; TIMBERING AND GROUT PIPES

TYPE A-UNTIMBERED ROCK
SHOWING
A, B, C, LINES AND DRIP PANS



TIMBER BULKHEAD USED FOR ARCH CONCRETE

PLATE 114.—Construction of Wooden Concrete Bulkhead and Method of Placing Drip Pans and Grout Pipes in Wet and Heavily-timbered Grade Tunnel. Bonticou South.



SKETCH SHOWING ORDER OF CONCRETING
BONTICOU TUNNEL (South)

PLATE 115.—Sketch Showing Method of Placing Concrete, Position of Forms, etc., for South Half of Bonticou Tunnel.

was found that the above described plant of travelers and derricks was unsuited to rough, open country on side hill, much work being necessary to shape the ground to carry the trestle, so that slow progress was made.

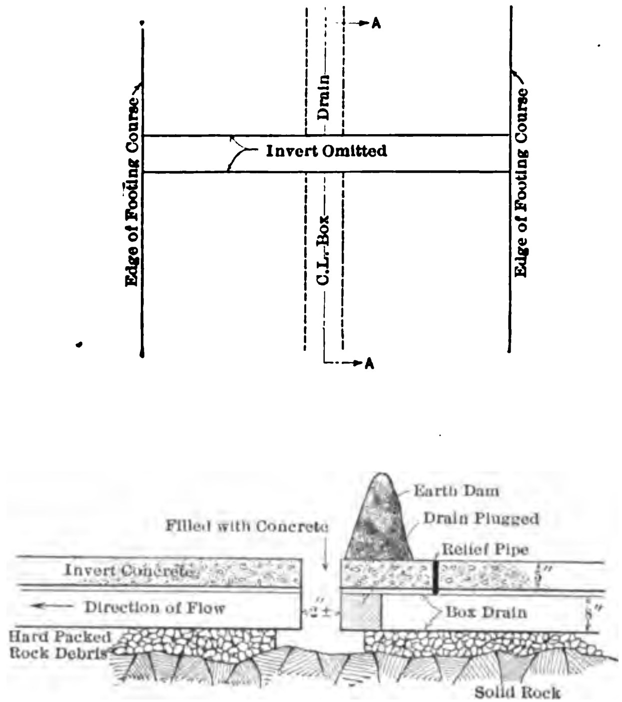
In advance of the travelers described, a $\frac{3}{4}$-yard Vulcan shovel excavated and spoiled on the downhill side except in deep cuts, where cars were loaded alongside and hauled to the dump. Occasionally the material was spoiled in the rear of the shovel to be picked up by the orange-peel bucket operated by the first derrick on the trestle. In a later arrangement an extra derrick was moved on skids in cut. The mixer was also moved to a central place, leaving only three travelers on the trestle, the central derrick placing the concrete with side-dump buckets.

Wooden Forms. During the first season the aqueduct was built with wooden forms similar to those used on Contract 10. After the invert was built, the side-wall forms were built in 15-foot sections to 8 feet above invert. The vertical ribs were 4 inches by 10 inches, 3 feet 9 inches apart, and were covered with 2-inch lagging and $\frac{1}{16}$-inch steel plate. They were adjustable by trench braces. The side-wall forms produced very good work, but the wooden arch forms, composed of 2-inch lagging supported by steel arched ribs hinged at the crown, proved to be slow and cumbersome. They distorted so much and made such a bad offset at the 8-foot line that they were later discarded in favor of the Blaw steel forms.

In 1910, working one shift per day, the plant placed 1335 feet of invert and 1065 feet of arch. In 1911, 2855 feet of invert and 2725 feet of arch were placed. During 1912 standard methods were employed, using steel forms, locomotive cranes, etc.

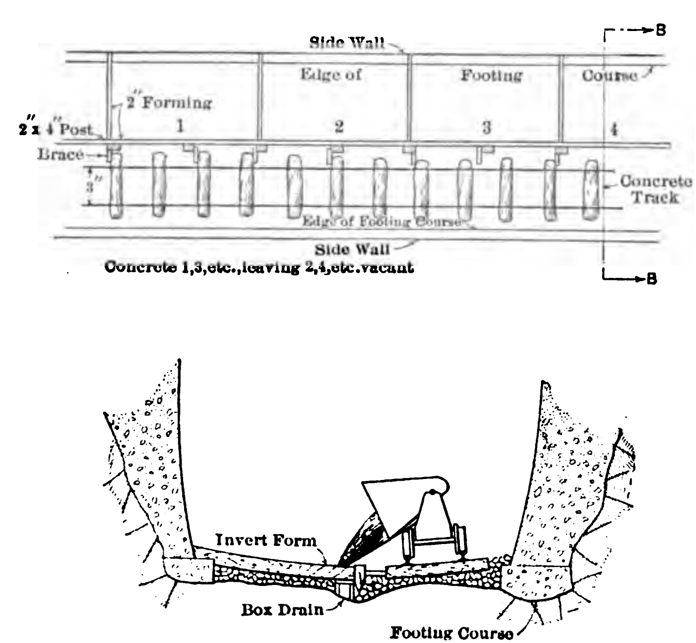
Shaft Sinking. For the sinking of the shafts the Dravo Company installed two temporary steam plants from which air was supplied by pipe lines to all six shafts.

The shaft-sinking organization from the Rondout siphon was transferred to this work together with the usual equipment of head frames, hoisting rig, etc. No trouble was experienced in getting down to rock except at Shaft 2, where an open caisson was sunk part way (64 feet), the rock being reached by timbering from the caisson. Three construction shafts were rectangular timbered shafts 11×22 feet. These shafts were put down in from six to eight months, the average progress of excavation and timbering being from 50 to 60 feet per month, the maximum about 90 feet. The contractor here, as on the Rondout siphon, exercised his option of



SECTION A A

PLUGGING BOX DRAIN



SECTION B B

CONCRETING INVERT

PLATE 116.—Method of Placing Invert in South Half of Bonticou Tunnel. Best progress was made by this method. Also method of plugging drain below invert.

sinking a larger shaft than required by the contract drawing, accepting payment on the bid price per foot. The three waterway shafts were sunk according to new specifications, requiring sinking and lining in stretches of not more than 100 feet; that is, after 100 feet of rock was exposed by the excavation, forms were inserted and permanent concrete lining placed, thus rendering timbering unnecessary.

Permanent Shafts. The permanent shafts are circular, about 14 feet 6 inches finished diameter. The excavation of the downtake shaft was taken out in a manner similar to that described for Shaft 1 of the Rondout siphon. While excavation was in progress on this shaft, a monthly advance ranging from 50 to 110 feet was made. This, of course, was interrupted by the concreting, which was placed in stretches of from 40 feet to 80 feet. Steel forms designed by the Dravo Company were used. These were built in quarter sections, 5 feet wide, and were internally trussed and braced, and collapsed with the aid of wooden keys. These forms gave a satisfactory and true surface for the waterway. Usually about two sections were filled per day, from a small concrete plant at the surface. The rock in uptake shaft, No. 6, proved to be rather wet and unsound, so that the placing of the concrete lining was a great advantage in securing this shaft. The progress per month was rather slow, the maximum being 77 feet of excavation and 91 feet of lining.

The details of shaft sinking and concreting are as follows:

Excavation of Construction Shafts. Compressed-air drills drilled four sets of holes, called sump, relief, bench, and end or side holes. The sump holes were started 6.5 feet each side of the center line, four on a side parallel with the center line, and were 10 feet deep, the butts being about 6 inches apart. The sump was shot and while being mucked the bar on which the drills were operated was set up. The remaining holes were 8 feet deep. A total of 28 to 32 holes were drilled, and the advance was about 5½ feet in five eight-hour shifts. Each shift consisted of foreman, 2 drillers, 2 helpers, 4 muckers, 4 topmen, 1 blacksmith and 1 helper.

From 35 to 97 feet of shaft were excavated per month.

Excavation of Circular Shaft (Shaft 6). Three circular rounds were drilled in one shift; next the sump holes were shot and mucked; next the side holes were shot and mucked; and next the rim holes were shot and mucked. Tripod drills were used. The drilling shift consisted of foreman, 5 drillers and helpers and 6 topmen. The mucking shift consisted of foreman, 7 to 10 muckers, and 4 topmen.

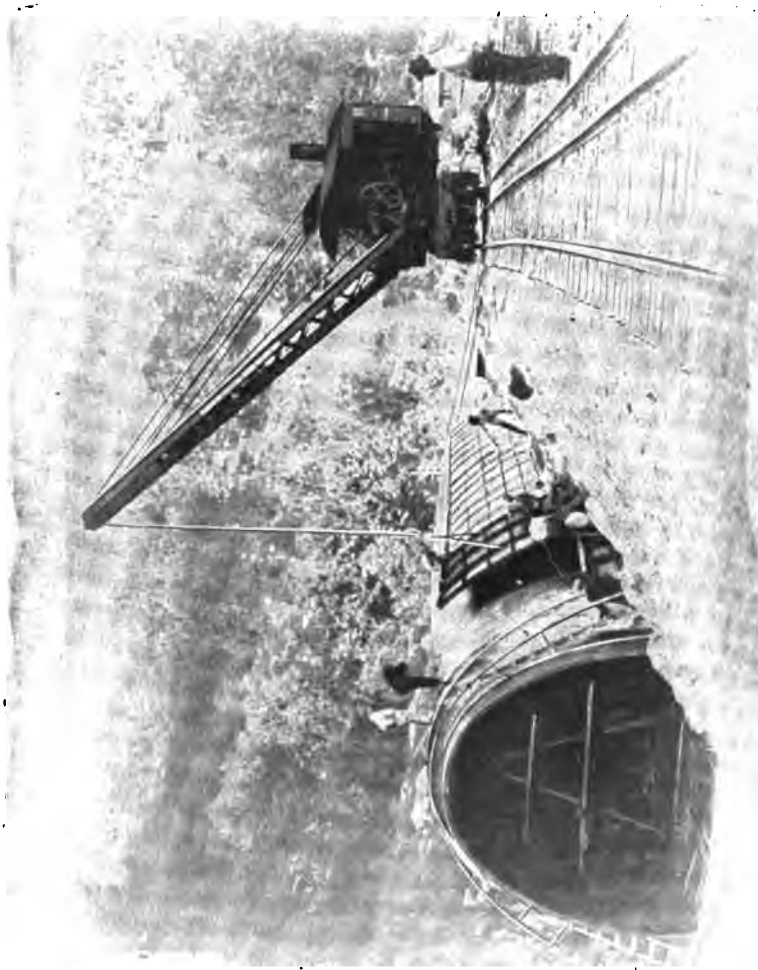


PLATE 117.—Moving Outside Steel Forms with Locomotive Crane.

The advance per day was 4.5 to 5 feet. Five sump holes were drilled 8 feet deep; 10 side holes 6 feet deep, and 16 rim holes 6 feet deep; 1.8 pounds of 40 to 60 per cent dynamite was used to excavate a cubic yard of rock.

Concreting Shaft 6. Circular wooden platforms in four sections were placed on braces at the top of the forms, and the concrete was mixed at the surface in No. 2 Ransome mixer and lowered in buckets and dumped directly into the space between forms. A chute was used to carry the concrete from the platform to the rock. The setting and filling with concrete of 8 forms (40 feet) constituted concreting operations. Two forms were usually set up and filled. Concreting then stopped until two more forms were set up and so on until 40 feet had been placed. The forms were left in place until the shaft depth was 60 feet from the bottom forms. A space of from 18 to 30 inches was left between the bottom of the old concrete and the top of the new, and this space was closed by wooden forms and filled by pouring grout into apertures left at the bottom of old concrete. Gravel or sand placed on the scaffold gave the bottom of the concrete an inclined surface. The scaffold which carried the forms was supported on four dead logs about 15 feet above the bottom of the shaft. It will thus be seen that 40 to 80 feet were sunk and concreted alternately.

Contractors' Railroad and Highways. While the shafts were being sunk, the main contractors were busy installing a central power plant and a 36-inch gauge railway. This railroad was laid along the line of the aqueduct from the south portal of the Bonticou tunnel to Shaft 5. Considerable work was necessary for the grading of the roadbed for the track, particularly along the line of the cut-and-cover. In addition, a substantial steel bridge was built across the Wallkill River to carry the railroad and a highway. Well-constructed roads were laid connecting the various shafts, so that access was readily obtained to them by teaming.

Quarry at Bonticou Crag. At the terminus of the railroad a quarry was opened up at the foot of Bonticou Crag. This crag is a steep cliff of Shawangunk grit, a very hard quartz conglomerate. The quarry and crushing plant were picturesquely located high above the railroad and were reached by an inclined track operated by a cable. It was designed to supply crushed stone to the cut-and-cover plants and all the shafts, but because of the hardness, seaminess and beddings (30° to 40° slope) of the rock and the unfavorable location of the quarry, it could do this only with considerable difficulty. At the beginning, the large boulders in the talus at the foot of the crag had a strong tendency to roll into the workings of the quarry and cramp men and plant. Drills had to be lowered down the face of the crag from a point 100 feet above, and great boulders loosened by the blasting were constantly rolling down, preventing the opening of a satisfactory working face. In the early stages of the work, these boulders often buried the track to the crusher. Considerable mud capping of these boulders was done, this being found to be more satisfactory than drilling. A No. 20 Marion shovel was employed to load 4-yard side-dump cars moved by gravity to the crushers and hauled back by mules.

Crushing Plant. During most of 1910 a No. 6 Kennedy gyratory crusher was in operation; later a No. 8 Kennedy crusher was installed, rated to deliver 125 to 200 tons of 3- to 13-inch stone to two No. 6 crushers. The revolving screens over the bins were 24 inches in diameter, 20 feet long, the perforations of the screens being $\frac{1}{4}$ inch and $2\frac{1}{2}$ inches. The main screen was partly surrounded by a jacket screen with $\frac{1}{4}$-inch perforations. The average output of the plant was 450 cubic yards per working day. During the winter of 1910-11 a storage pile of approximately 20,000 cubic yards was accumulated. This was fortunate, as in May, 1911, a fire destroyed the bins and screen house, and the pile was nearly exhausted in the month required to rebuild them. During the working season the output was very close to the demand, and at times 600 cubic yards were daily shipped to the working. The stone dust for the concrete was mixed with natural sand in the proportion of one part to two. About 80 to 100 men, 3 air drills and 6 mules were employed at the quarry. The drills averaged about 4 feet per hour.

Wear on Crushing Plant. As in the case of the grit quarries on Contract 12, the stone was found to be very severe on the wearing parts of the crushing plants and screens. A set of concaves for the crushers lasted about three months. Three complete sets of revolving screens were worn out in less than two seasons, together with practically the entire conveyor system. The quarry, though very favorably situated to supply stone to the entire nine miles of the work, proved to be expensive in operation, owing to the hardness of the rock and the difficulty of keeping working space in a quarry on a steep slope at the foot of a high cliff with a talus of huge boulders.

Progress Made During 1909. By the end of 1909 all the shafts of the siphon had been sunk and the headings turned, with the exception of two terminal shafts completed shortly afterward. The central power plant was built between Shafts 4 and 5 to furnish air and electric power along the entire pressure tunnel. The plant was operated by electricity furnished by the Poughkeepsie Light, Heat and Power Company, which controlled a system of power plants and transmission lines, so that it was pretty safe to figure on a constant service. Two of their plants were hydraulically operated, others by steam at three Hudson River towns, tied together so that power could be obtained from any one plant. As a favorable rate for electricity was quoted, it was decided to use electricity rather than steam, as in the Contract 12 plant.

Power Plant for Wallkill Tunnel. The plant was housed in a steel building and operated entirely by electricity, using 33,000 volts three-phase alternating current. At the plant the current was stepped down to 2200 volts, and divided into three circuits—one for the air compressors, the other two for the shafts, for hoisting and for lighting and operating electric equipment consisting of electric pumps, ventilating fans, electric locomotives, concrete-mixer motors and machine-shop motors. The compressor circuit operated motor-driven belt-connected two-stage air compressors, two built by the Laidlaw-Dunn-Gordon Company, and three by the Ingersoll-Rand Company. These required 2300 H.P. with an output of about 11,700 cubic feet of free air per minute, at 100 pounds gauge pressure. From the power house to the shafts the air pipes varied from 12 inches to 6 inches. The force required to operate the plants was 1 chief engineer, 3 compressor enginemen, 3 electricians, 3 oilers, 1 wiper, and 1 laborer. From Aug. 31, 1910, to Jan. 4, 1911, which covered a period of tunnel driving, 3,562,000 K.W.H. were metered at the central plant.

Hoisting Equipment. Permanent timber head frames were erected in which were operated two balanced cages. The Lambert hoist installed at each shaft with drums 66 inches in diameter was connected to a 150 H.P. three-phase 2200-volt motor, equipped with solenoid brakes and overwinding devices. The cages operated at the usual speed of 400 feet per minute. In addition, ventilating fans and pumps were also electrically operated. Some trouble was experienced with the electrical equipment, but this was finally overcome.

Power Consumption. Careful records were kept at the power plant and at the shafts of the consumption of electricity and air for various purposes. It is very unusual to obtain reliable figures for power consumption for a work of this magnitude, and the following are given:*

* Much of the following information on the tunneling of the Wallkill siphon was obtained from an article by Assistant Engineer Raymond Hulsart, *Engineering News*, Oct. 20, 1910.

Power Consumption.	Compressors.	Hoists.	Lights, Blowers, etc.	Total.
K.W.H. per day	25,300	2780	1570	29,650
K.W.H. per cu. yd. exc.	30.2	3.3	1.9	35.4
K.W.H. per 1000 cu.ft. free air compressed to 100 lbs.	2.5			

Consumption of compressed air:

Drills per Day.* Cubic Feet Free Air.	Pumps per Day. Cubic Feet Free Air.	Leakage in Mains and Other Losses per Day.	Total per Day.
5,545,000	3,855,000	720,000	10,120,000

* Includes air used for blowing smoke.

Drills Used.	Cubic Feet Free Air.
Per shift, (4½ hours' drilling)	25,900
Per minute, including stop	96
Per minute while actually running	166

The pressure of air varied from 95 pounds at Shaft 4 to 80 pounds at Shaft 1 and 85 pounds at Shaft 6, the air being transmitted through 25,000 feet of pipe varying from 12 inches to 6 inches in diameter.

Electric Locomotives and Tunnel Equipment. At three of the shafts electric locomotives were used in the tunnels and on the dump. They proved to be successful and were considered more economical and efficient than the mules at the other shafts. The entire tunnel equipment proved to be efficient and economical, particularly in the power consumed. The compressed air was furnished in ample quantities for all drilling purposes. It was used, in addition, to a considerable extent in clearing the headings after blasting supplementing an efficient blower plant and to some extent for pumps.

Method of Tunneling. For the excavation, the ordinary top heading and bench method was used at all the shafts, the bench being carried within about 100 feet of the face of the heading, and the tunnel trimmed as it advanced, the aim being to obtain immediately a completed tunnel, so as to leave little to be excavated at the final trimming. Little water was encountered in these tunnels, the maximum quantity pumped from all being only 600 gallons per minute.

The entire pressure tunnel was excavated during the year 1910 at

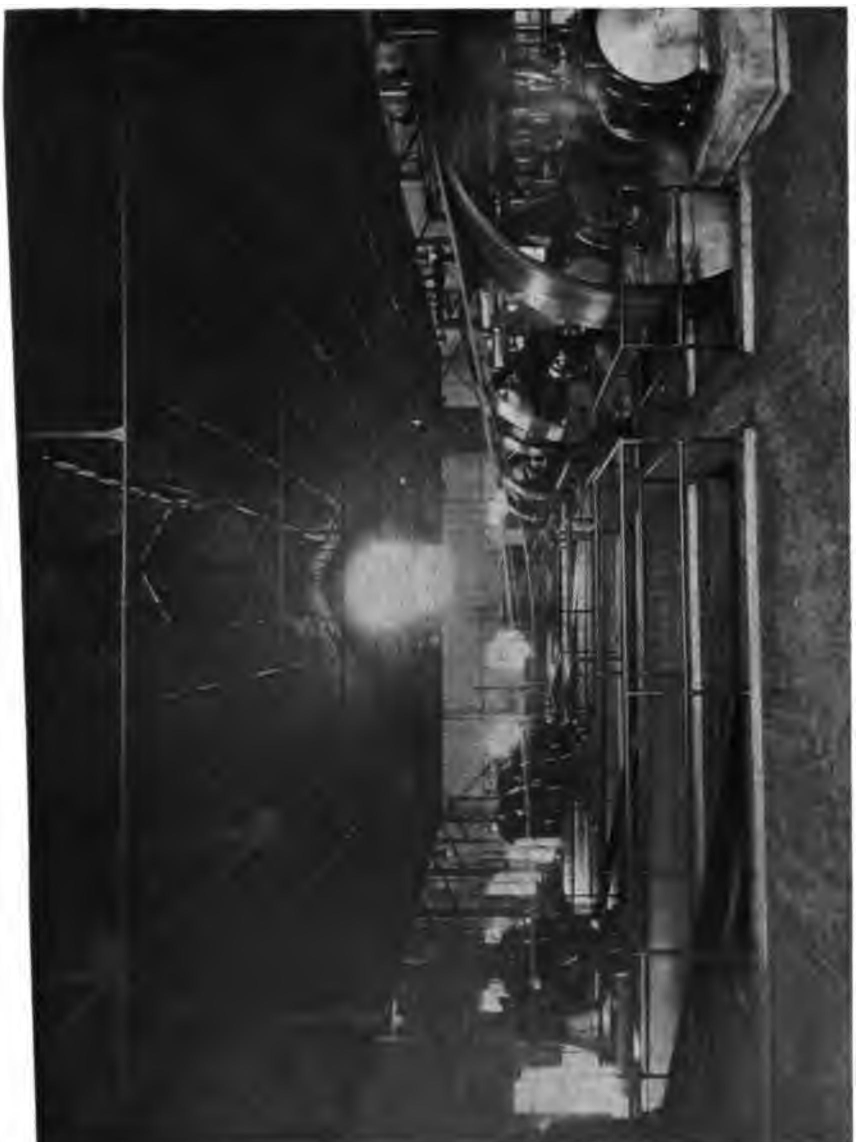


PLATE 118.—Contract 47. Compressor Plant. Capacity 11,700 feet of free air compressed to 100 pounds. Machines were all belt-driven Laidlaw-Dunn and Ingersoll-Rand. Power mostly obtained from hydro-electric plant at Honk Falls, about 20 miles away.

a high average rate of progress. This was favored by the uniformity of the rock formation and the fact that so many headings were going at the same time, offering an opportunity to compare the work of different shaft organizations, each of which was in charge of an efficient superintendent and foreman, some of whom were fresh from similar work on the Rondout siphon.

The first pair of headings were holed through in July, the others following until January, 1911. In 1910, over 23,000 feet of tunnel were driven from six shafts and ten headings. Many of the tunnels averaged considerably over 300 feet per month. The maximum progress was 523 feet at Shaft 3 north, this being for the completed circular tunnel about 10 cubic yards per foot. This is probably the best progress made to date in the United States for a tunnel of this size driven in hard rock. A detailed account of the method used is given elsewhere.

Ventilation. The ventilation of a siphon tunnel during excavation is of great importance, but in most of the tunnels it can hardly be said that the plants were very successful in clearing the smoke after blasting, this being responsible for delays in waiting for tunnels to clear and the hampering of the men while actually at work. Among the most successful ventilating plants were those used on the Wallkill siphon. Sturtevant blowers capable of furnishing 7500 feet of free air at 6½-ounce pressure were used; 12-inch galvanized iron pipe was brought within 300 to 400 feet of face of heading. Though the plant was rigged up to either blow or exhaust it was found more advantageous to blow fresh air into the heading, forcing the smoke to the shafts. The blower worked about twelve hours in twenty-four. In addition, during blasting, compressed air was liberated as an aid to the blowing plant. In this way a minimum time was lost due to smoke and gas in the tunnels. On some of the other contracts good ventilating plants were installed, but they failed to properly clear the tunnels, due to use of either too small blower pipes or, more commonly, to leaky joints in the pipes.

The tunnel was well lighted by 16-candle-power lamps every 25 feet. The water was pumped to the surface by air pumps, six of 200-gallon capacity and four of 100-gallon capacity. Worthington centrifugal pumps, two of 100 and two of 200-gallons capacity, were also installed, but were only occasionally used.

Details of Tunnel Excavation. The tunnels were excavated by the ordinary top heading and bench method, the bench being kept within about 75 feet of the base of the heading. Two eight-hour drilling shifts were used in each heading. They ordinarily

PLATE 119.—Contract 47. Tripod Drills on Bench which Usually Followed about 75 Feet Back of Face of Heading.

accomplished the work of drilling and shooting the heading about as follows:

	Hours.	Minutes.
Setting up drills	1	45
Drilling	4	30
Removing drills		15
Loading		30
Shooting		45
Balance		15
Total	8	00

The heading holes were drilled in three rounds by four drills mounted on horizontal arms clamped to two columns. The bench was drilled by two drills on tripods. Ingersoll-Rand and Sullivan drills were both used. About 189 feet of hole were drilled per round, about 6 feet per cubic yard of heading, and only 1.8 feet per cubic yard of bench. The heading ordinarily ran 5½ cubic yards per foot and the bench 3¾ cubic yards. About 4.6 pounds of 60 per cent Forcite dynamite was used per cubic yard of heading, and 1.4 pounds in bench. Between each drilling shift there was a four-hour interval which was used to muck heading sufficiently to set up drills. Three eight-hour shifts of muckers were used, who were able to work about nineteen hours in twenty-four.

Force Used to Excavate Tunnels, Record Month. At a shaft with two headings in operation, 260 men and 8 mules were employed, 6 drillers with their helpers constituting a drilling shift for each heading. Usually an advance of 6½ feet was made per round; with two rounds per day, this would give a progress of about 13 feet, but the daily progress from month to month ran from 9 to 12 feet at the various headings. The record progress of 523 feet per month was made by drilling unusually long holes in the heading, 12-foot steel being used for the cut holes, giving an 8.7 foot advance per round. To facilitate the work here, two drillers and helpers set up the columns in the four-hour interval between the regular drilling shifts. The record was made pretty well toward the end of the work with a picked force, and it is significant only as it shows what can be done under very favorable conditions. The average progress per heading ranged from 265 feet to 356 feet per month. The slower progress is accounted for by difficulty of drilling the sandstone strata encountered. Some of this rock was very hard, requiring from fifteen to twenty hours to drill a round. The ordinary shale of the remainder of the tunnel was rather easily drilled, the drills averaging 10½ feet per hour, including changes of steel.

Plate 120.—Contract 47. Compressed-air Drill as Mounted on Column and Arm in Heading of Wallkill Tunnel. Usually headings were drilled by four drills mounted on two columns.

To facilitate mucking, steel plates were so placed that the blasted material fell upon them. The five hours lost from mucking is accounted for as follows: Taking down runways, twenty-five minutes; shooting, sixty minutes; replacing runways, thirty-five minutes; two hours each shift, and one hour for lunch. Where electric locomotives were used the $1\frac{1}{2}$ yard steel side-dumping Koppel cars, of which there were twenty-four at each shaft, were hauled by mules from the bench to a siding 200 feet away. There they were made up into trains of three and four cars and hauled to the cages by electric locomotives. One locomotive was found sufficient for one pair of tunnels, and was more economical than entire haulage by mules.

The force for twenty-four hours at one shaft for two headings was as follows:

260 men and 8 animals

	No.	No. of shifts.
Superintendent	1	1
Asst. superintendent	1	1
Master mechanic	1	1
Hoist runner	1	3
Blacksmith and helper	2	3
Mechanic	1	2
Pipeman	2	3
Carpenter	1	1
Electrician, day shift	2	1
" night shift	1	2
Signalmen and cagemen	4	3
Heading foremen	2	2
Drillers and helpers	12	2
Jap drillers	2	1
Nippers	2	2
Waterboys	2	2
Powderman	1	2
Muck bosses	2	3
Muckers	40	3
Trackmen	2	3
Trolleyman	1	3
Dump boss	1	3
Dump men	3	3
Drivers	4	3
Mules	4	2

Concreting of Invert. The third season was devoted almost entirely to concreting. Before the invert was placed the tunnel was trimmed to the prescribed lines and the loose muck in the bottom removed. Separate concrete plants were installed at four of the shafts, the crushed stone being delivered to them from the Bonticou quarry, also from a crusher plant erected at Shaft 5 to use the tunnel muck from the sandstone layers. The invert was

PLATE 121.—Contract 47. Electric Trolley Locomotive Used for Hauling Concrete for Lining Wallkill Tunnel. These locomotives enabled much better progress to be made than where mules were used.

concreted by the use of continuous side forms, the method followed being the same as that on Contract 12, except that the concrete was dumped directly into the forms from the cars run on a track over them, instead of being wheeled by hand from a platform. The entire invert concrete was placed, starting half way between the shafts and working toward them. The invert was 5 feet wide with radial joints 10 inches deep, the bond being a groove. Below the form the concrete was allowed to flow out level, filling in the low points, this making it much easier to prepare the bottom for the side-wall forms.

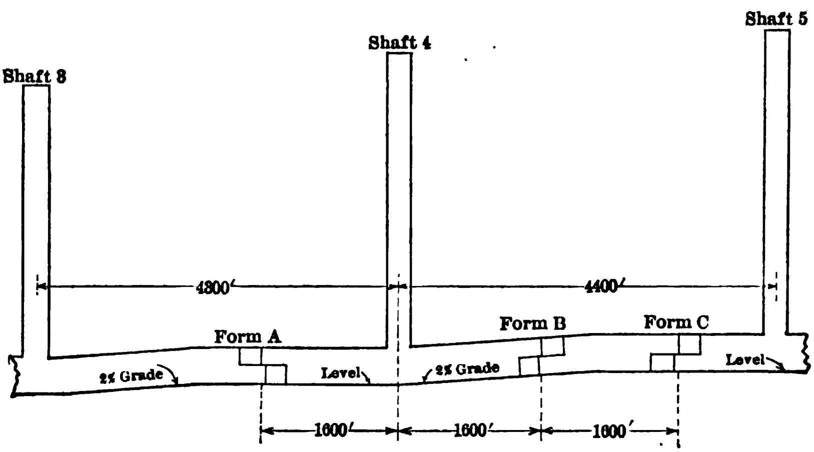


PLATE 122.—Contract 47. Profile of Portion of Wallkill Pressure Tunnel, Showing Position of Forms for Concreting Lining.

Concreting Side Walls and Arch. Blaw forms for side walls and arch were used, equipped with carriages similar to those used on Contract 12, and were collapsed and used in the same way. The forms here used were improved by being longitudinally braced and having the vertical posts bolted to the form instead of being pin-connected, as on Contract 12. A few stretches were concreted in two stages, but mainly the method of working the side-wall and arch forms together, known as the trailing form method, was used (see Plate 125). In this manner very good progress was made in concreting. At first 40-foot side-wall arch forms were used, but these were afterwards lengthened to 50 and later to 60 feet. Three sets of forms were usually used at each shaft, one set being concreted each day, usually in less than sixteen hours. The shaft mixing plant was run at a high rate, filling Youngstown cars which were hauled in trains of three and four to the foot of the incline. The incline was a light steel structure built to be easily dismounted and moved. Electric hoists on the rear end of the platform hauled the trains up the incline and to the long platform serving both side wall and arch. The concrete was shoveled into the arch forms as fast as possible, the remainder being used for the side walls. By the time the arch forms were filled and partly keyed up, the side-wall forms were filled, after which a second small shift of specially picked men built the remainder of the key, in a manner similar to that described in the Rondout siphon, using radial boards and key-plates. At some points the side-walls were not started until late in the afternoon but were completed about the same time as the arch. Generally fourteen working hours were taken to fill a 60-foot section of arch and side wall, using for the day shift four or five spaders and twelve shovelers; for the night shift four spaders and twelve shovelers. Five men shoveled directly into the key at one time. The keying-up gang consisted of five men closing on a bulkhead at the free end of the form.

Concreting Key with Blocks. An endeavor was made to shorten up the time of keying the arch by the use of two separate gangs, making closure by means of a concrete block. This block was cast with radial ends and parallel sides 19½ inches by 22 inches and placed through a 20″×20″ hole in the form, after which angles were bolted onto the plate to hold the block, which was grouted in place through a pipe cast in it. Although this method of keying was at first considered to effect a considerable saving of time, it was not much used, it probably being found that it was unnecessary as the keying-up gangs became more proficient.

Progress Made on Tunnel Lining. The best progress made on tunnel lining was as follows: In Shaft 2, 1670 feet of side wall and 1652 feet of arch placed in one month of thirty days. In Shaft 5, 1737 feet of arch and 1133 feet of side wall in one month. At Shaft 2 three sets of arch and side-wall forms were used, the concrete being placed every day of the month except one. At Shaft 5 two sets of arch and side-wall and one arch form was used, the concrete being placed every day. Clearances were such that the electric locomotive could pull the cars through the forms, but this was a source of some trouble, as derailments were apt to occur. The forms were found to work very well, there being no difficulty experienced in getting a set ready every day. As the concreting took only a little more than one shift, plenty of time was available for a separate gang to move and set forms, clean up tunnel, etc. The

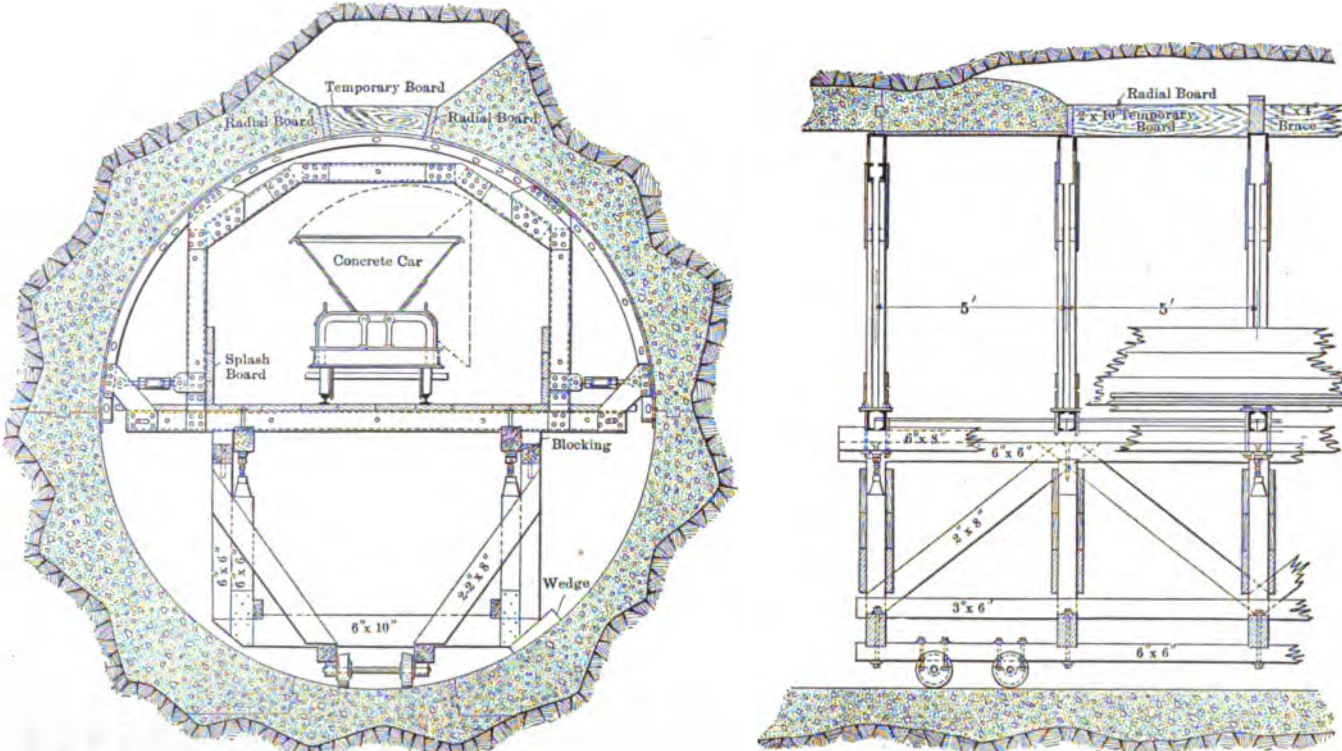


Plate 123.—Contract 47. Construction of Steel Blaw Forms and Wooden Carriage, as Used for Concreting Arch of Wallkill Tunnel. Forms were 60 feet long and were concreted in about 16 hours.

increased progress made in the Wallkill tunnel over the Rondout was largely due to the use of electric locomotives instead of mules, and the use of trailing forms.

Ransome Form. A trial was made of full-circle forms built by the Ransome Company. The forms were made in unit lengths of 5 feet bolted together. The forms were collapsed on a special carriage, the working platform traveling on a car of its own. The forms did not prove practicable or economical, as they could not be separated into arch and side walls and cars of concrete could not be pulled through. Only a little more than 100 feet of concrete was placed before their use was discontinued.

Protection of Green Concrete in Wet Areas. In general there was much less trouble from water on the Wallkill than on the Rondout siphon, so that the placing of drip pans over wet areas and grout pipes was not such a feature. However, there were several stretches quite wet. One 50-foot section passed 25 gallons of water per minute. Here it was necessary to pan the entire roof, the water intercepted by these pans being led to five 2-inch pipes on each side. On the Rondout siphon it was customary to place drip pans to cover wet areas of rock, the water intercepted by these pans being led away by grout pipes passed through holes in the forms, cut where needed. This was the practice at first on the Wallkill siphon. Later an endeavor was made to simplify the work by leading all water to pipes placed in a few fixed positions. This reduced the number of holes in the plates of the forms. These positions were as follows: Elevation about 2 feet above inner edge of invert, just below springing line, and 3 feet above the springing line. The pipes placed were straight, leading to the bottom of the drip pans placed above their level. The drip pans were made of light sheet metal braced to the forms or nailed to wooden plugs driven in holes drilled for this purpose. Another method was to pan all leaks above the springing line to pipes just below it. By this method a pipe was placed just below the top of the side-wall concrete and carried to a pan placed against the rock as usual. This pan was carried 2 feet or more above the side wall and its free end later connected with pans brought down from higher leaks. This method has the advantage of taking away all grout pipes from the arch except those placed in the key, and it leads away all the water so as not to affect the arch concrete. The disadvantages of placing grout pipes only in fixed positions are as follows: It leads to the placing of large and long drip pans, so that the leaks cannot be gotten at as directly as when drip pans are used to cover only wet

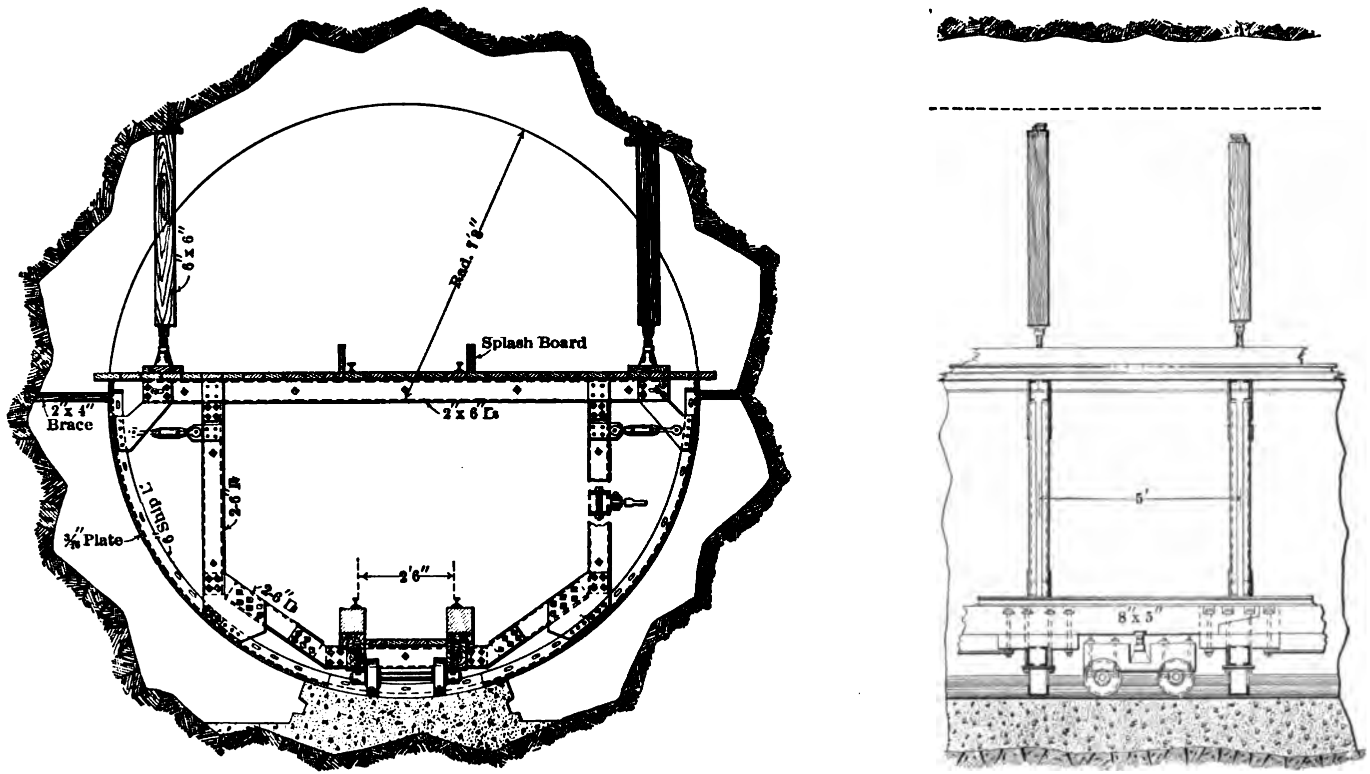


Plate 124.—Contract 47. Construction of Steel Blaw Form and Carriage for Moving Form, as Used on Side Walls of Wallkill Tunnel. This form in 60-foot lengths usually followed or trailed the arch form so that both were concreted at a time, in about 16 hours.

areas, the grout pipes leading directly from them. In grouting it is an advantage to be able to clean out pipes after grouting and regrout. It is but little trouble to cut holes in the plates to take a short nipple from the coupling end of grout pipes. Some very wet areas were passed on the Rondout siphon by the use of separate drip pans and grout pipes as weepers, the concrete between the pipes showing up very dry and tight.

It is the opinion of some of the engineers that 60-foot sections of arch are too long, as when contraction takes place due to lowering of temperature after setting of concrete, cracks are apt to open up between joints, leakage through these cracks being very hard to cut off by grouting. On all the contracts a large percentage of arch sections, where over 45 feet long, have been found to be cracked.

Test of Tightness of Concrete Lining. A very interesting test was made on the Wallkill siphon to ascertain the tightness of the concrete lining against external pressure. It was found that the leakage through grout pipes and joints so relieved the ground water that very little pressure was obtained from it even when the pipes were closed in a section. At a wet point between Shafts 4 and 5, the leakage through grout pipes was found to be 20 gallons per minute in 180 feet. To isolate this section and prevent the running of water along the tunnel arch, the adjacent sections were grouted.

All the weepers and grout pipes were plugged and the resultant ground water pressure ascertained by a gauge. This in three days rose to a maximum of 40 pounds, being relieved at this point by

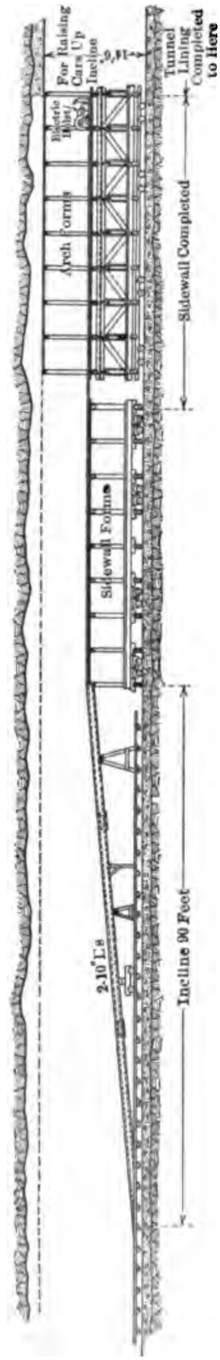


PLATE 125.—Method of Using Trailing Side Wall and Arch Forms, as Used for Wallkill Pressure Tunnels. Also later for Rondout, Moodna, Croton, and City Aqueduct Tunnels. By this method progress was much increased over the separate use of side walls and arch forms with corresponding economy.

some leakage through five transverse arch joints. A connection was then made to Shaft 5 pump discharge pipe, which raised the pressure in the space over the tunnel arch to a maximum of 135 pounds. The maximum leakage through the five expansion joints was only 7 gallons per minute. A peculiar feature of this was that this leakage rapidly diminished in about one week to less than 2 gallons. Damp areas on the concrete increased somewhat, but the amount of water seeping through the concrete was less than one-half gallon per minute, a large part of the arch under pressure being entirely dry. Longitudinal joints in key and side wall leaked very little.

This test would indicate that the arch lining, which averages here about 20 inches in thickness, can be relied upon to be very tight. It must be remembered that this section had not been grouted at the time of the test, and that the grout will probably make the concrete lining of the tunnel still tighter against external pressure. However, there is no direct relation of internal to external leakage in a tunnel of this character, as at a place where water comes in freely through a joint, outward-moving water would have to penetrate hundreds of feet of rock in very minute seams. On the other hand in some cases where there is access to a reservoir of ground water, water may more freely escape than enter the tunnel.

Grouting of Tunnel. The Wallkill pressure tunnel was grouted after concreting by the continuous method, no attempt being made to build cut-off walls. The grout was forced over the arch under a low pressure (about 80 pounds), connections being made about every 150 feet, working from shaft to shaft. A few high pipes were kept open and subsequently grouted under high pressure and also served as vents and telltales. The weeping pipes in side wall were grouted under pressure or plugged with mortar by hand, these pipes being left open to the last to keep water pressure from accumulating on the arch.

The final leakage into the tunnel for its 4½ miles was about 82 gallons per minute. Considerable time was saved by using wooden plugs instead of valves, at telltale pipes not connected to, and by plugging pipes with mortar by hand where connections with grout pipes were deemed unnecessary. High pipes were kept open when deemed necessary by ramming a plug of oakum to the upper end. This could readily be removed before grouting, thus saving considerable time otherwise used in drilling out pipes for regrouting.

Comparison of Eastern and Western Tunnels. In this connection it is interesting to compare the records and methods of the contractors on the Catskill Aqueduct with those in the West.

Very good progress has been made in the past few years at various water tunnels at Los Angeles and through the Rockies. Over 1000 feet per month was made in a rock tunnel on the Los Angeles Aqueduct, but the material was a soft sugary rock taken out with the aid of augers, and is, therefore, not in the hard-rock class. However, in the Elizabeth Lake Division, which constituted the hard rock section, a progress of 604 feet was made during the month of April, 1910, using Leyner rock drills.

Laramie-Poudre Tunnel. The best progress on record for the United States with rock drills in hard rock was made in the tunnel connecting the waters of the Laramie and Poudre Rivers in Colorado.* This tunnel has a cross-section of about $7\frac{1}{2}' \times 9\frac{1}{2}'$ in width intended to be drilled so as to give an approximately rectangular section. The tunnel is 11,306 feet long and was driven between January, 1910, and August, 1911. At the west end of the tunnel, working down grade, the average progress per month was 308 feet. The average progress at the east end per month was 474 feet for nineteen months, 509 feet per month for sixteen months, and 525 feet per month for the last year of work, with the record of 653 feet for March, 1911. This seems to be far in excess of any other American tunnel heading on record.

The tunnel was driven entirely in heading from two portals, using two No. 8 Leyner drills mounted on a horizontal bar, and a third drill less than half the time, 2.4 drills being above the average. Two settings of the bar were necessary for each round which was drilled to give a long advance (10 to 7 feet), there being twenty-one holes 10 to 12 feet long drilled for this purpose. Three shifts of from 2 to 3 drillers, 2 helpers and 4 to 6 muckers and 1 foreman were used. Fuses were used to fire the shots, thirty minutes being lost after each shot to permit the heading to clear of smoke, after which the drill-bar was set in its upper position while mucking proceeded, iron plates being used to make the shoveling easier. The wages paid were very high, \$4.50 to drillers, \$4 to helpers, and muckers \$3.50, blacksmiths \$4.50, drivers \$3.50, and foremen \$6. In addition, a liberal bonus was paid for work beyond a certain speed. The rock excavated was a hard gray and red granite, requiring little timbering.

Comparison of Wallkill with Laramie-Poudre Tunnel. Conditions, it will readily be seen, were far more favorable for rapid progress at the Laramie-Poudre Tunnel than on the Wallkill Siphon. The Wallkill tunnel has a circular section about 18 feet in diameter,

* See Trans. Am. Soc. C.E., 1912.

requiring heading and bench, 10 yards per foot, as against the rectangular section 7.5′×9.5′ of about 2.5 yards per foot, less than one-half the yardage of the Wallkill headings alone. The small section allowed the use of the horizontal bar, impracticable for the larger circular section. Very much more careful work was necessary in the circular pressure tunnel to shape the rock for the concrete lining. The Laramie-Poudre tunnel is to be lined only in the timbered sections. Better progress can be made in a grade tunnel where long trains of cars can be hauled to the portals instead of to shafts, where delays are apt to occur. The Laramie-Poudre tunnel was practically a drift or heading of a section to admit of rapid driving. The face was drilled with a great number of long holes loaded to within 2½ feet of the collars with 100 per cent blasting gelatine and 50–60 per cent dynamite, so as to pulverize the rock, excess breakage not being objectionable, as in the circular Catskill tunnels, where expensive concrete lining was necessary. Fuse firing was practiced in the tunnel in common with most Western tunnels, resulting in a considerable saving of time, as all the fuses can be touched off at once, the sequence of shots being determined by varying the length of fuse. For some reason, firing by electricity is almost universal in Eastern tunnels, probably due to the belief that fuses are more liable to miss fire.

Comparison of Alpine Tunnels and Laramie-Poudre Tunnel. The Laramie-Poudre tunnel affords the nearest approach to Swiss tunnel methods and progress yet made in this country. The heading was about the same size and shape as the bottom heading of the Swiss tunnels and the methods were very similar. The horizontal drill bar is used in the Alps, but is usually supported on a carriage mounted on wheels instead of being carried in by hand. Percussion drills (Ingersoll-Sergeant and Meyer) have also been used on the Loetschberg, where the maximum tunnel progress has been made. The headings also are rapidly drilled with many holes and shot heavily with 85 per cent dynamite, shattering the muck in small bits onto iron plates, from which it is shoveled. The first step is to make a passage for the drill carriage carrying four or five drills. Much shallower rounds are drilled in the Alps (about 4 feet) but many more advances per day (4 to 6) are made. The Loetschberg tunnel made from 18 to 25 feet per day with a maximum monthly record of over 900 feet. The greater speed is obtained by (1) thorough organization for a long job, usually five years, (2) permanency of tunnel force, who are compensated for extra good work on the bonus system, and (3) superior plant, manifested mostly in the ventilating outfit and spraying of headings while drilling and after blasting. The Loetschberg tunnel used fans 11.5 feet in diameter, furnishing 53,000 cubic feet of air per minute at 5.5 ounce pressure. Compressed air was also freely used during the blastings. Drill carriages, shallow advances and large charges of high explosives (over 6 pounds per yard of 85 per cent dynamite) were used.

The wonderful organization of the Swiss tunnel is shown by the immense amount of work carried on just back of the heading. Upraisers are made every 500 to 600 feet and the tunnel enlarged to full size, timbered and lined without interfering with heading progress. The Loetschberg tunnel was double tracked, about 25 feet wide, 22 feet high, with semicircular top and masonry lining 2 or more feet thick.

Cost of Swiss Tunnels. The cost of the Swiss tunnels is much higher than American tunnels, although the scale of wages is much lower, drill runners getting only $1.00 per day, muckers $0.80, and masons $1.00. The bonus paid on the Loetschberg tunnel increased the pay about 75 per cent. Original estimated cost per foot was $211, a notable decrease, however, over the earlier Swiss tunnels.*

The American tunnels are rapidly approaching the Swiss tunnels in speed of driving, at the same time lowering the unit costs so that there is little need of copying Swiss methods *in toto*, although there are several features of Swiss tunnel practice which make toward both speed and economy which have not as yet been adequately realized in this country.

Details of Swiss Tunneling. The driving of a Swiss tunnel can be compared to the serving and firing of a big gun where by military precision every second is made to count. In the Simplon tunnel the following program was followed while drilling in antigoric gneiss

Bringing up and adjusting drills	20 minutes.
Drilling	1 hour 45 minutes to 2 hours 30 minutes.
Charging and firing	15 minutes.
Cleaning away débris	2 hours.
Or for one whole advance of 3 ft. 9 in.	4.5 to 5.5 hours.

resulting in a daily advance of 18 feet, despite high rock temperatures (about 95 degrees) and floods of hot water. In the Simplon tunnel Brandt hydraulic drills were used, but as good progress was made

* The writer is indebted to a paper read by W. L. Saunders before Am. Inst. Mining Engrs., in 1911, for valuable information about Alpine tunnels.

later in the Loetschberg tunnel, on the same railroad, by the use of pneumatic drills. In the Loetschberg tunnel the following schedule for tunnel advance of 3.5 to 5 feet was followed:

Fifteen or sixteen heading holes were drilled in 1.1 to 1.5 hours. Loading and firing of holes took only a few minutes, 6 to 8 pounds of 85 per cent dynamite per yard being fired by fuses. Quantities of compressed air were freed at the heading, the fans kept going and the face and muck sprayed, enabling mucking to be started within five minutes after firing. The tunnel muck was rapidly shoveled from the iron plates to the cars. The men worked in relays, resting after filling a cubic meter car (36 cubic feet) in five minutes. Another gang then filled the second car, etc. As much as 14 car loads have been taken away in ninety minutes.

American Tunnel Progress. To attain the high speed of the Alpine tunnels a large force of highly trained men is necessary, so that it would seem that with the much higher wages prevailing in the United States, the Swiss tunnel progress will probably not soon be attained. With the shorter tunnels here this would appear to be entirely unnecessary. This is best illustrated by the Laramie-Poudre tunnel, located in one of the most inaccessible regions of the United States in the heart of the Colorado Rockies. The tunnel plant had to be hauled 65 miles over the roughest mountain roads, this being accomplished in the dead of winter. To supply power for the compression and dynamos, the Poudre River was dammed and piped to a power house at one of the portals, and utilized with Pelton water wheels. Work on the plant began Dec. 1, 1909, and the tunnel was driven between January, 1910, and August, 1911. It would seem that, if we can do all the work of installing plant and a camp in an inaccessible mountain region and drive a tunnel over 2 miles long in less than two years, and that with a much smaller force than used abroad and at a much smaller cost, we can be satisfied with our progress in tunnel driving during the last few years.

CHAPTER X

WALKILL VALLEY CUT-AND-COVER AQUEDUCT

Contract 15

Contract 15 Prices. This contract, comprising 3 miles of cut-and-cover aqueduct on the Wallkill division south of the Wallkill tunnel, was awarded to Elmore & Hamilton Contracting Company, September, 1908, the total contract price being $933,000. Due to the gravelly nature of the earth, loose earth section was entirely used, except for a short stretch partly in rock. Prices obtained for a few of the main items are as follows:

Open-cut excavation	cu.yd.	$0.45
Refilling and embankment,	"	.25
Concrete masonry,	"	5.50
Portland cement,	bbl.	1.55

On the basis of contract quantities and prices the 15,900 feet of this contract will cost the city $58.73 per foot.

Connecting Track and Gravel Bank. The work of this 3-mile stretch offered no special difficulties, except that suitable concrete material could not be obtained on the right of way, the rock excavated being rather soft Hudson River shale. During the first season a standard-gauge track was laid from the south end of the contract to the Wallkill Valley Railroad, about 3 miles distant. This track passed near a deposit operated by a company with whom the contractors had arranged for a supply of sand and gravel. Several test pits dug here indicated great thickness of gravel, but when the excavation was started, after a complete plant composed of steam shovel, cars, sand-washing machinery, screens, etc., was installed, it was found that only a small percentage of the material excavated was gravel, the remainder being sand. This caused a delay on both Contracts 15 and 16, for which this company had contracted to supply gravel. Gravel deposits are commonly over-estimated, the proportion of gravel usually running much smaller than anticipated. There has hardly been a deposit discovered

PLATE 126.—Contract 15. Steel Forms and Locomotive Crane for Building Cut-and-cover Aqueduct. Continuous method was here used, forms being used "telescoping." 60- to 75-foot section concreted daily.

along the entire line of the aqueduct sufficient to yield any considerable quantity of coarse material.

Plant Used on Contract 15. Contract 15 must be credited with introducing methods which in many respects have become standard, and with first showing what could be accomplished with the locomotive crane. After a certain amount of work had been done with small steam shovels and wagons, a Marion 60-ton steam shovel was equipped with a specially long boom made by the same company. This shovel had a clear lift of 26 feet from top of rail to bottom of open dipper, and a reach-out of 40 feet from the center of the track. Working one shift per day, with a force of 9 men, from 15,000 to 26,000 cubic yards per month was excavated, averaging 19,000 cubic yards. The shovel was started from the south end, working at subgrade and piling excavated material on the downhill side, and at the same time grading for a railroad to run along the bank. Along this track was operated a double-truck Bay City locomotive crane having a 40-foot boom. The crane was equipped with a clam-shell bucket which dredged the material along the deeper cuts, depositing it further downhill, and removed the bottom trimming excavation. In this manner the standard-gauge track was extended as fast as the steam shovel excavated.

Concreting Plant. A long stretch of invert was laid, and on this was erected 300 feet of Blaw collapsible steel forms operated in the usual manner. The concrete was mixed in 1¼ cubic yards Smith mixer located at a stationary plant at the south end of the contract, which was later moved to a point 3000 feet south of the north end. The concrete was loaded into bottom-dumping 1-yard Steubner buckets, 5 being placed on each of two large flat cars and hauled by two 35-ton American locomotives to the work, and dumped into the invert or arch by a large locomotive crane. The feature of the 1911 plant was its great simplicity and at the same time its great capacity. The mixer was mounted on a timber tower, so as to discharge directly into a storage hopper holding four batches. With a batch in the mixer, this was a train load, permitting the continuous operation of the mixer and speedy loading from the storage hopper directly into the buckets. The sand and stone bins over this mixer were filled by a large derrick operating a 1¼-cubic yard clam-shell bucket. During the night sand, gravel and stone were hauled to the plant and dumped on the slope of an adjoining side hill. The derrick could easily raise sufficient material, including cement, to enable the mixing plant to supply 300 cubic yards of concrete in one eight-hour shift. This is noteworthy in com-

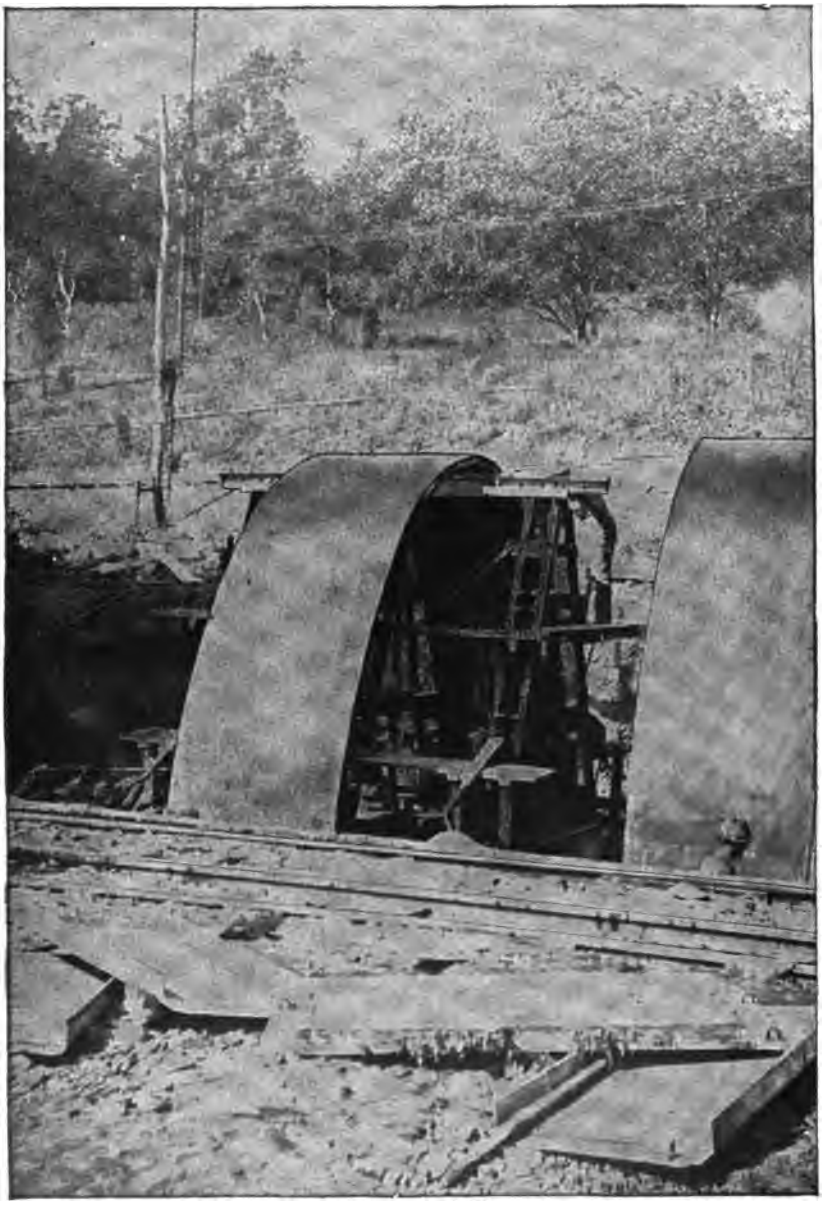


PLATE 127.—Section of Inside Form—5 Feet—Being Moved to New Position and Turned around to Form Curve. Sections are wedge-shaped for 200-foot radius curve.

parison with the much more elaborate plant usually operated on other contracts. The standard-gauge equipment also demonstrated its superior advantages and capacity, as no difficulty was met with in transporting the concrete over the single track.

Unfortunately this contract was hampered by lack of gravel, so that it was necessary (in 1911) to equip and operate a crushing plant at Rosendale many miles distant. Just when the quarry was in satisfactory operation, Mr. Elmore died, so that the company was obliged to go into the hands of a receiver, with a consequent delay in the work. Nevertheless, the contract will be finished nearly on time, due to the speed made by the receivers with their well-planned method of work.

Refill. After the arch was built, the excavated material was dredged out by the locomotive cranes operating either the clam-shell or orange-peel buckets and was dumped over the aqueduct. About 200 cubic yards of refill was placed by each crane in eight hours. A criticism might be made of this method, in that it is difficult to shape the embankments to the prescribed lines and to clean up the excavated material along the right of way. Steam shovel and trains were also used during part of 1910 and 1911 to make refill over the aqueduct.

Steel Forms Used. A good deal of trouble was experienced with the forms used during the first year, these being the same forms which were superseded on Contract 11 and other places by heavier forms. The contractor found, however, that by the use of five bolts connecting the inner and outer forms and by rigidly bracing the bottom of the forms very good service could be obtained. The forms here were always used telescoping, the work proceeding continuously from the south end. During the year 1911 the average concrete placed in a month, working one shift every day, including Sundays, was 1362 feet, the maximum progress being 1740 feet in 27 shifts in October, 1911.

Rock Cuts. In the rock cuts a good deal of excavation was removed in skips by derricks or by the locomotive cranes, the steam shovel in these places only removing the earth to the rock.

The total force working on the contract varied from 120 to 180 men.

PLATE 128.—Blaw Outside Forms for Cut-and-cover Aqueduct. They are in 5-foot panels, moved and placed by locomotive crane. Held in place by bolts to inside form.

PLATE 129.—Contract 15. Laying Alternate Blocks of Invert for Cut-and-cover Aqueduct. Concrete mixed at stationary plant, hauled on cars and placed by locomotive cranes. Blaw steel profiles used, surface rolled with steel shafting. On this contract excavation and invert were kept far in advance of arch.

Contract 16

Contract Prices. This contract for cut-and-cover aqueduct for $2\frac{1}{2}$ miles at the northern end of the Newburgh Division was awarded to the King, Rice & Ganey Co., in March, 1909, the total contract price being $610,000. Some of the principal items are as follows:

Open-cut excavation...........	50 cents per cubic yard.
Refilling......................	25 cents per cubic yard.
Concrete masonry.............	$5.15 per cubic yard.
Portland cement...............	1.50 per barrel.

On the basis of contract prices and quantities the 12,700 feet of this contract will cost the city $48.06 per foot.

Plant and Methods. The construction was all simple cut-and-cover aqueduct, the firm earth type predominating. The excavated material was mostly compact earth, underlaid in most places by a few feet of shale rock. The track built by Elmore & Hamilton was extended so as to serve this contract, which was also to be supplied with gravel from the bank near the Wallkill Valley Railroad. Standard-gauge equipment, as on Contract 15, was used throughout. The plant installed was very complete and has been described, with a good deal of justification, as a model aqueduct building plant. The excavation was started at the extreme south end of the work with a 90-ton Marion special steam shovel, following the precedent set on Contract 15, equipped with a long boom with a lift of 26 feet and a cast of 35 feet. Working one shift per day, excluding Sundays, the average excavation per working month in 1910 was 14,000 cubic yards; in 1911 was 16,000 cubic yards. Work under this contract was carried on under a very compact plan, the entire operation of excavating, concreting, and refilling being completed within a distance of 700 feet. The steam shovel worked just ahead of the invert, loading material on a temporary standard-gauge track on the uphill side of the cut. The main running track on the downhill side was previously graded and laid for the entire length of the work. As soon as a short section of arch, from 50 to 200 feet back of the shovel, had been completed, the back fill was made from the side-dump cars loaded directly by the steam shovel and hauled to and fro by standard-gauge dinkies. When no spoil area was available over completed arch, the excavated material was carried ahead and spoiled temporarily on the center line and rehandled later instead of being placed in permanent spoil banks, which on this contract would have been unsightly and undesirable. Just ahead of the invert a movable derrick was constructed, operating in the bottom of the cut on a specially wide-gague track (16 feet) which was laid and taken up as fast as the derrick advanced. This derrick placed the key-block concrete and removed all the material from trimming which was loaded in skips by hand. It was found, however, that the main steam shovel could excavate, even firm earth section, very close to line, leaving only a little in the bottom to be removed.

Concreting of Aqueduct. During the first season Blaw forms were used, operated in the usual manner, the concrete being obtained first from a small Hains mixing plant. Later this plant was replaced by a rotary Smith mixer. The bins over the mixer were supplied by a bucket conveyor, sand and stone being dumped directly into the feeding hopper from standard-gauge cars. Work was considerably handicapped by lack of gravel, so that the company was forced to buy stone in various places. It was exceedingly difficult to obtain a sufficient supply of rcushed stone by railroad, emphasizing the ad-

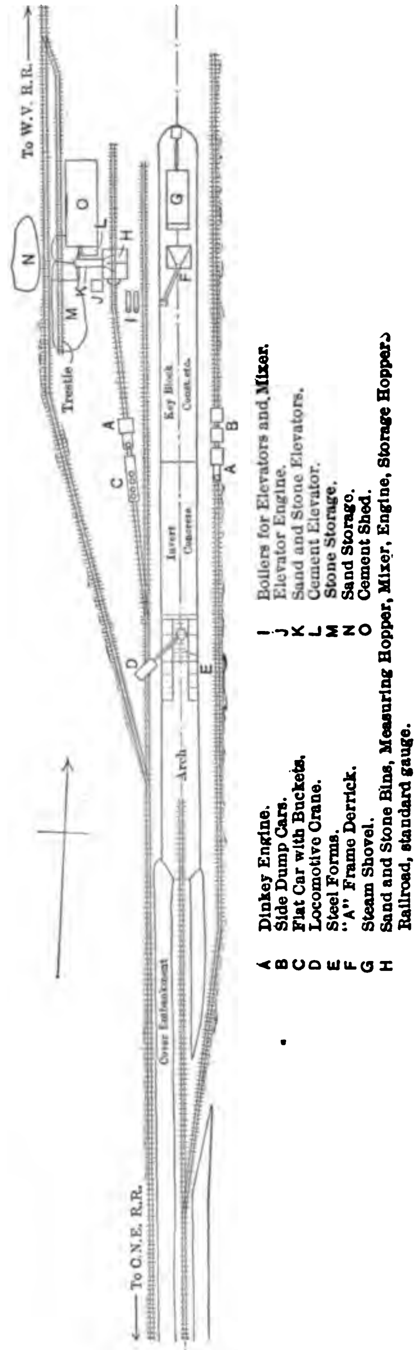


PLATE 130.—Contract 16. Diagrammatic Layout—not to Scale—of Plant for Building Cut-and-cover Aqueduct. Operation complete in distance of a few hundred feet. Plant and method very successful.

Plate 131.—Special 90-ton Marion Steam Shovel with Long Boom. Lift 26 feet, cast 35 feet. This shovel excavated full depth of cut to close lines and filled cars on banks which were dumped over completed aqueduct. Machines similar to this were extensively used on Catskill Aqueduct construction.

vantage to a large construction in the country, of an independently operated quarry and crusher. As on Contract 15, the concrete was loaded directly from the mixer into bottom-dumping buckets and hauled on a single flat car to the work. When the distance was not too great, a single dinky could haul sufficient concrete to complete one section of about 200 yards in a few hours, running at times at the rate of 30 miles an hour, a speed which could not be obtained with narrow-gauge equipment.

King, Rice & Ganey Steel Forms. During the second season forms designed and built by the contractor were in use. These forms, shown on Plate 132, were made of ¼-inch steel plate with a single hinge at the top and truss members from the hinge to the bottom spaced at 5-foot intervals. The plate was stiffened longitudinally by purlins. The forms were of 5-foot rectangular sections, the curves being obtained by wooden fillers. They were not telescopic and collapsed only enough to permit them to be moved through the completed arch. They rested on a large wooden sill placed on invert with wedges under sill. Steel pipe braces with jacks at one end were used to prevent the sides from coming in during the placing of the concrete. The forms were struck by knocking out wedges, then prying out the wood sills, and with steel wedges loosening the forms from the concrete, after which the side screw-jacks were used to provide clearance to move ahead and to adjust forms to line. A screw-jack on the carriage lowered the forms, which were then moved ahead 15 feet at a time. The outside forms were plates reinforced in two directions with angles and moved in 15-foot lengths. Connecting the forms were steel tapered bolts. These bolts, which were first used in Contract 11, are known as Irwin quick-fastening bolts. They have no threads, being set up and removed by the use of a steel key fitted between a slotted nut and a slot in the bolt itself. They saved considerable time over the bolts ordinarily used, and as they were of correct length, also acted as spacers. They were heavily tapered, and being made of hardened steel could be used many times. The inside forms were moved on a simple A-frame car running on the invert, the spacing out method being used. The outside forms were moved by a Browning locomotive crane, which was also used for placing the concrete. Nine men working one-half shift moved the inside forms, 85 feet of which could be set up in four hours. Seven men moved the outside forms in four hours. With this plant, a 60-foot stretch of invert and arch was readily placed in a day, working only one shift; at times 75 feet, and even 90 feet (two 45's).

Rock Excavation. When rock was encountered, it was hard to keep the excavation sufficiently ahead. A Keystone well-digging machine was used to bore holes through the overlying earth and into the shale bottom, which was blasted ahead of the steam shovel. In these places it was necessary to work the shovel two shifts to keep ahead.

Progress Made. During 1910, working one shift per day, excluding Sundays, an average of 970 feet of arch was placed in a working month. In 1911, the average per month was 1040 feet. The last concrete arch was placed Aug. 30, 1911, and the entire work was accepted early in 1912, being the first aqueduct contract entirely completed.

Merits of Contract 16 Methods. It is probable that the work on Contract 16 was the most economical on any contract, showing a high average output per man. It is well to note that the work was very simple and well served by a direct railroad connection over which cement and other materials were readily and cheaply delivered. The country is almost level, so that there were no deep cuts or special work to break up the work into parts.

The method of excavating and immediately using material for back filling was one favored by the engineers, as the concrete arch is immediately covered up and protected from the weather and the work is at all times kept clean and in good shape. It is, however, hardly practicable in places where deep and irregular cuts are encountered, nor can it be economically carried out in solid rock cuts, which have to be excavated a long way ahead to keep the concrete plant going at full capacity. The work on Contract 11 brings out these points especially well. Better progress can probably be made by stripping rock ledges with the steam shovel for some distance, and then backing the shovel to subgrade and excavating the remaining ledge by use of steam drills, picking up the shattered rock with the shovel, rather than by the method of drilling through the overlying drift with well drills as described above.

Typical gangs working on concreting were 38 men; on earth excavation, 27 men; rock excavation, 35 men; on earth refill, 15 men, and rock refill, 30 men.

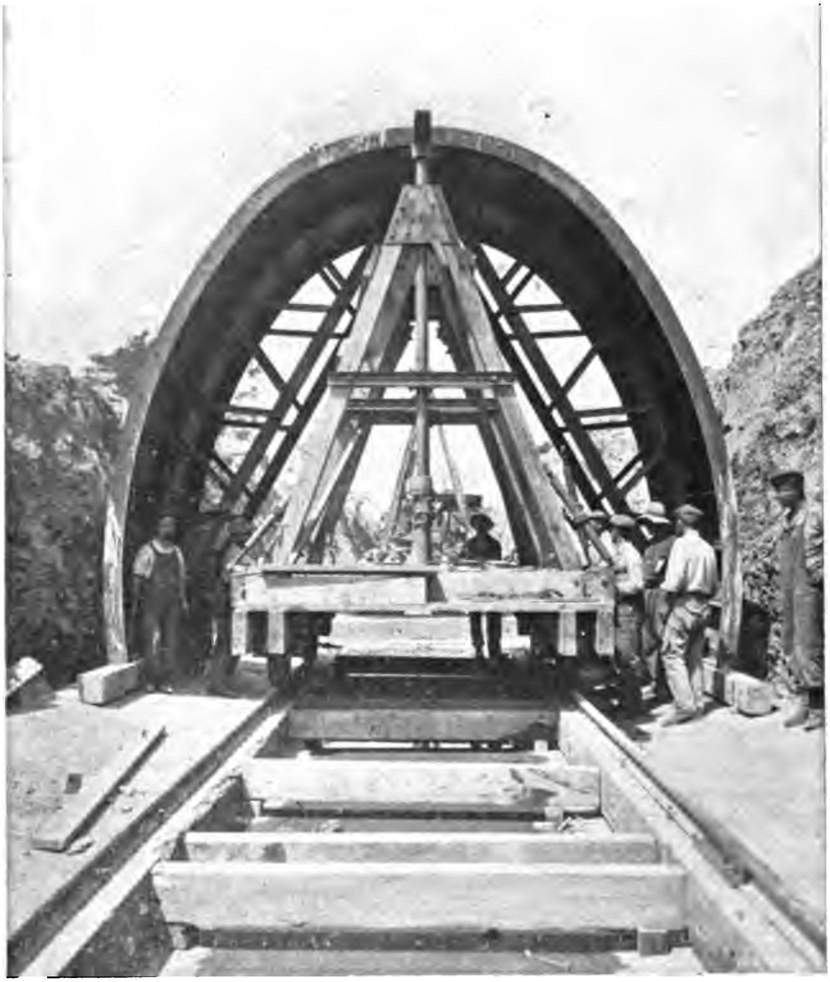


PLATE 132.—Contract 16. Steel Form—King, Rice & Ganey. Form has only One Joint, at Crown, and was Easily Moved by Carriage Shown. Hydraulic jacks raised and lowered forms, sides were pulled in by ratchet-jacks on side. Form was non-telescoping and very successful for "spacing out" method of building cut-and-cover aqueduct.

Contract 17–18

Contract Prices, Contract 17–18. These two contracts, comprising about 5.6 miles of cut-and-cover aqueduct of the Newburgh Division, were awarded April 19, 1909, to the American Pipe & Construction Co., for a total $1,558,695. The principal prices on Contract 17 were as follows:

Excavation	.39 to 1.00 per cu.yd.
Refill	.25 to .35 per cu.yd.
Concrete masonry	5.25 per cu.yd.
Portland cement	1.50 per barrel

Contract 18:

Excavation	.38 to 1.60 cu.yd.
Refill	.25
Concrete masonry	5.25 per cu.yd.

On the basis of contract quantities and prices the 14,100 linear feet of Contract 17 will cost the city $51.24 per foot, the 15,600 feet of Contract 18, $53,60 per foot.

Railroad and Camp. During the first season, a standard-gauge railroad was built the entire length of Contract 17 and half the length of Contract 18. A large central camp was established to accommodate sufficient men for both contracts. This camp was one of the best along the line of the aqueduct and is worthy of a brief description. It was located on a high knoll with natural drainage from the camp on all sides. Fifty houses of 8 men capacity (3200 cubic feet of air space per house) were built north and south of the main street. The American camp on the north had buildings identical in design with the Italian camp on the south, except that kitchens with cook stoves were provided for the Italians in small lean-tos built against their houses, whereas since the American laborers do not cook their own meals, the kitchens were not provided for them. The main buildings were a hospital, having a ward of six beds, with doctor's office, isolation room, and bathrooms, a washhouse for Americans, a dining-room and kitchen for Americans, contractor's office, a commissary and Italian bakery. The water was supplied from a driven well pumping into an elevated wooden tank. The Italian camp was provided with a laundry and washhouse. Five hundred feet from this camp and 50 feet below was located the contractors' stables, the tool shop, the blacksmith's shop, etc. The camp was kept very clean, all refuse being incinerated.

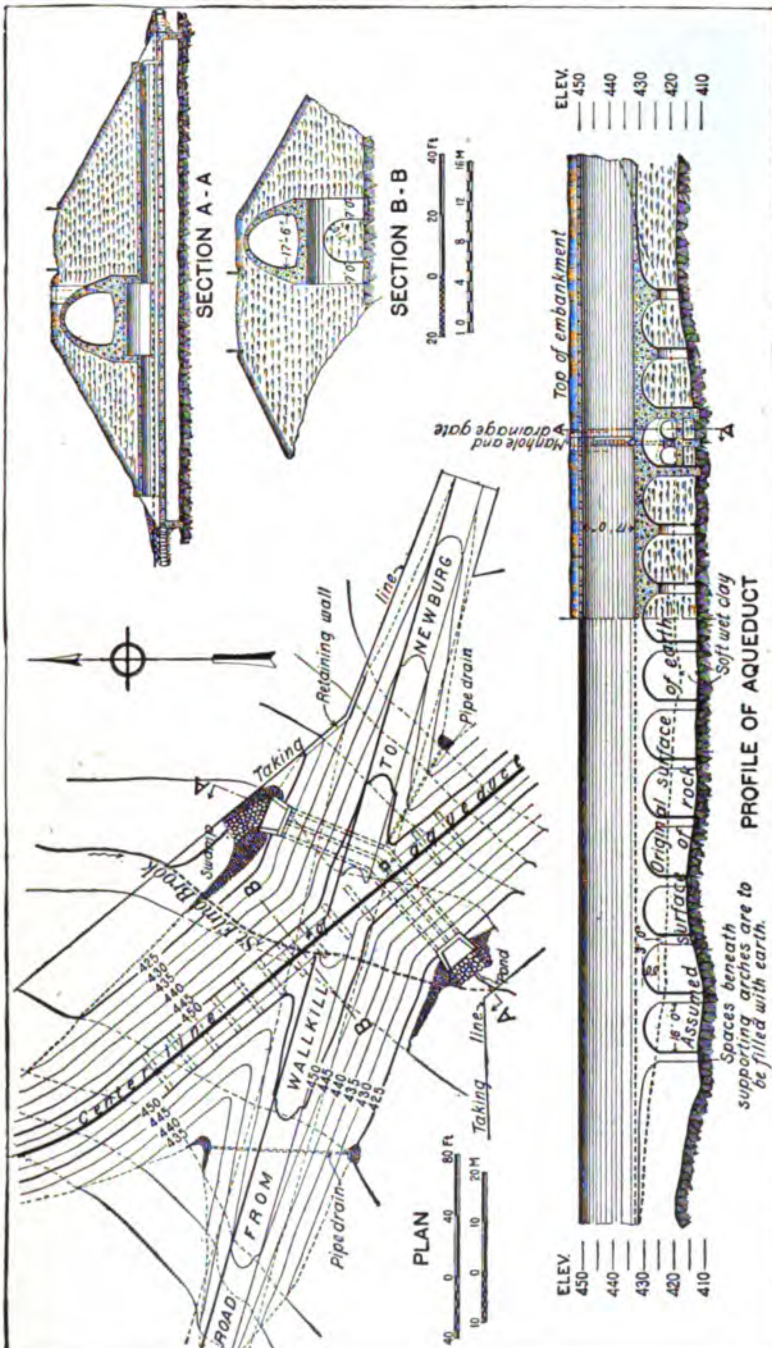


PLATE 133.—Special Construction at St. Elmo Crossing.

Special Features of Contract 17–18. The only two features of importance on this contract are at the crossing of the New England Railroad, and the St. Elmo brook. At the railroad, the standard aqueduct section is used, but reinforced with steel rods, so that where depressed below the railroad it will stand at a slight head. At St. Elmo brook, to avoid a high embankment, the aqueduct is carried on a viaduct. The piers for this viaduct are carried down to bed rock, the earth between left in place and shaped to form the intrados of the arches supporting the invert of aqueduct. The ordinary concrete arch is then placed on this and covered over with earth filling, the final appearance being the same as the usual cut-and-cover aqueduct. Two of the transverse arches are used to form a culvert for St. Elmo brook.

Excavation with Scraper Bucket. Excavation was started at St. Elmo brook, using a Lidgerwood-Page-Crawford excavator operating a drag scraper bucket. The material contained a large percentage of boulders and this excavator did not work satisfactorily, the boulders preventing the bucket from obtaining a full load of earth, or overturning the bucket while at work. The excavator worked more successfully at another point where the trench had fewer boulders. It was necessary, however, to use a gang of 10 or 12 laborers, trimming on one side of the trench, while the excavator worked on the other side, the laborers shoveling toward the center line. In this way the steep slopes of the firm earth section were maintained. This operation, however,was found to be very costly, and the excavator was replaced by a steam shovel, but was used for a time to place cover embankment from material spoiled at the sides. It was unsuccessful in this and was removed from the work.

Methods of Excavation. In a long rock trench in Contract 18, a 60-ton Marion steam shovel was operated, removing blasted rock in three cuts. The rock was a shale interbedded with hard sandstone in such a manner that however carefully blasted the breakage lines were so uncertain as to produce a cut varying widely each side of the required section, the sides zigzagging back and forth along various cleavage planes. The spoil from the cut was placed on an area provided at the north end of the cut. This contract is noted for the variety of excavating machinery used. At some points movable A-frame derricks were erected in the trench. These operated Owen grab buckets, which resemble a clam-shell with the addition of steel teeth for digging. The steam shovels loaded partly on cars and a portion of the time spoiled alongside the cut. The material spoiled was reexcavated by grab buckets to make the fill over the arch.

PLATE 134.—Excavating Trench for Cut-and-cover Aqueduct—Firm Earth Section—Using Scraper Buckets. Machine is assisted by gang of men shaping up sides, etc. Concrete invert placed.

Owego Steel Forms. The steel forms used on this contract were built by the Owego Bridge Company, and were made to concrete a section of the arch to 8 feet above invert. After building a short stretch it was found, however, much better to build the entire arch in one operation, and the forms were thereafter so used. The first forms were hinged at the top and jointed at the 8-foot level, but required considerable interior bracing. The outside forms were steel panels very heavily trussed, to avoid the use of tie-bolts. This made them rather clumsy to use and it was difficult to place concrete. This was later obviated by the use of a V-shaped dumping saddle. The later forms had hinged joints 2 feet above the invert instead of the bolted joint at 8 feet. The forms were designed to be used telescopic, but were collapsed only sufficiently to permit moving them through the completed arch, setting ahead on the invert and working back to the completed section. Fourteen men working on day shift and 8 men on a night shift moved and erected the arch forms.

Concreting Methods. An unusual method of mixing and placing concrete was employed in 1910. Instead of mixing concrete directly at a central plant, what is known as a proportioning plant was used. At this point, buckets were loaded with dry cement, sand and stone in the proper proportions. A supply train consisting of a standard-gauge locomotive with two flat cars, each car carrying 12 one-yard side-dump buckets, operated between the proportioning plant and the mixer, which was located alongside of the arch to be concreted. A locomotive crane placed the dry material in a rotary mixer, which discharged the concrete into Steubner bottom-dump buckets, which were raised and placed between the forms by another locomotive crane. This method made necessary a double track wherever the concrete was being placed, in order to make the scheme at all satisfactory. There was apparently no good reason for not mixing the concrete at the proportioning plant and carrying it directly to the arch to be placed in the usual manner by a locomotive crane, such as was done on Contracts 15 and 16. What was aimed at in this contract was probably to avoid the transportation of wet concrete for long distances. It was found, however, on Contract 11, that concrete could be readily transported a distance of over 6000 feet without material separation or setting. On Contract 17, in 1911, the concrete was mixed at a central plant near Station 1605, and was hauled and placed as on Contract 16.

Crushing Plant. On Contract 18, a large crushing plant was installed. It was operated for a time with stone obtained from walls. The supply of walls for a considerable distance was soon exhausted and recourse was had to a sandstone quarry. For heavy concrete work such as the aqueduct, it was found that only a limited amount of stone could be economically obtained from walls, as the haul soon passed the economic limit.

Progress Made. On Contract 17 about 3500 feet of aqueduct was completed in 1910, the best month's work being about 700 feet; on Contract 18, about the same amount of work was done. During 1911, 6189 feet of aqueduct was concreted on Contract 17; on Contract 18, 6510 feet of arch. The concreting work was completed in 1912.

Contract 45

Contract 45. Work and Prices. This contract comprises 5⅓ miles of cut-and-cover aqueduct at the lower end of Newburgh Division. The only special features of this contract are three heavy foundation embankments of a maximum height of 20 feet and a heavy rock and earth cut about 7000 feet long, averaging 33 feet in depth with a maximum of 60 feet. The contract was awarded in June, 1909, to the Pittsburgh Contracting Company, for a total of $1,675,290. The main prices are:

Open-cut excavation	0.57 per cubic yard.
Refill and embankment	.27½ per cubic yard.
Concrete masonry	5.25 per cubic yard.
Portland cement	1.30 per barrel.

On the basis of contract quantities the 28,189 feet of this contract will cost the city $59.56 per foot.

This contract was divided into two natural parts by the Washington Square pipe siphon. North of this, connection was made with the Central New England Railroad over the tracks laid over Contract 18. A portion of the trench in a heavy rock cut was excavated by 60- and 90-ton steam shovels, the material being used for back fill and embankments, and in spoil banks.

Experience with Scraper Buckets. A distinguishing feature of this contract was the extensive use made of 3 Lidgerwood-Page-Crawford excavators, which operated scraper buckets and did all the main trench excavation excepting the above mentioned heavy cut. The record made by these excavators on Contract 45 working in glacial drift with some boulders is rather poor when compared with steam shovels. They rarely excavated more than 10 feet of complete aqueduct trench of 12 to 14 feet cut in one shift of eight hours, or about 60 cubic yards, whereas the steam shovel in like material could make from 50 to 60 feet.

In comparing the excavator and shovel for aqueduct purposes, the following was experienced on this contract: (1) The steam shovel generally moves along on level ground in the cut, whereas the Page excavator works in advance of the cut, and therefore must go along the grades of the original ground. In wet ground this may be an advantage, as the cut tends to drain the water away from the surface, leaving the excavator on dry ground. (2) The number of men needed for the excavator is about the same as that for the shovel. (3) The excavator cannot progress through very bouldery or hard material at nearly the rate of the steam shovel, which digs with a rigid arm with powerful leverage; working much like the human arm it can throw boulders and stumps to one side without difficulty. (4) The excavator machinery is more frequently out of order on account of the difficult going. (5) In soft ground, the excavator has the advantage in that it has a longer reach and can dig a very deep or very wide cut in one lift and without changing its position. This is the work for which the excavator was developed and where it reaches its maximum efficiency. The steam shovel undoubtedly excavates closer to line, leaving less of expensive trimming work to be done. In this connection it may be noted that the shovel (Plate 131) used on Contract 16 averaged per month during 1910, 14,000 cubic yards, and in 1911, 16,000. The shovel worked mostly only one shift except in rock, when two shifts were occasionally worked.

Crushing and Mixing Plant. In concrete work crushed field stone was largely used. The first plant contained two crushers and a set of sand rolls. Later, two plants were built without the sand rolls, as they were not successful. The mixing plants were located at the crushers, one-yard mixers discharging directly into bottom-dumping buckets, hauled on flat cars over the narrow-gauge road to the point of concreting, where their contents were placed over steel Blaw forms in the usual manner by locomotive crane.

Monell's Fill, Largest on Aqueduct. The largest fill to support the Catskill Aqueduct is that constructed under Contract 45, and known as Monell's fill. This fill is 975 feet long, 90 feet wide at a point $2\frac{1}{2}$ feet above the invert, 188 feet wide at the widest point of the bottom, and 23 feet high at this point. It contains 68,000 cubic yards of material below $2\frac{1}{2}$ feet above the invert, of which 37,000 cubic yards is rolled embankment. The rolled embankment portion extends 25 feet each side of the center line at $2\frac{1}{2}$ feet above the invert and, except for about 175 feet at each end, where the sides of the rolled portion are vertical, it has side slopes of 1 on 1.

Stripping of Top Soil. The site of this embankment was a saddle, the water draining freely away on each side. It was cleared during July, 1909, and the stone, among which were many loose boulders, was hauled to the crusher. The top soil was removed during August, 1909, by a Lidgerwood-Page-Crawford excavator with the scraper bucket, and stored along the sides. This machine was very satisfactory for the work, handling about 4500 cubic yards in three weeks, working two shifts per day, and removing all stumps, roots, etc.

Making the Fill. The construction of the embankment was started August 30, 1909. The contractor obtained permission to build the rolled portion of the embankment first, placing on the sides only sufficient material to support it.

The remaining part of the sides was ordinary fill, 22,000 cubic yards in all, and was dumped over the sides from the tracks along the top in the spring of 1911, after the rolled portion had been completed.

The material used was hardpan, very difficult to dig, with a high percentage of boulders in places. It compacted readily and very solidly. It was obtained from the aqueduct trench and from borrowpits alongside the same. It could be plowed to a depth of 3 feet below the surface, and the excavator would dig it to a depth of 6 feet below the surface. Below that it was more economical to blast.

Rolling the Fill. On the fill, to insure a solid embankment and one that would not settle, the work was done as follows: The site was thoroughly rolled, all stump holes being filled with hand-rammed material. The earth was then spread in a horizontal layer about $4\frac{3}{4}$ inches thick before rolling, the surface covered being thoroughly wet just before spreading. A 12-ton road roller, having a wide-grooved front wheel and two large cleated rear wheels, then passed forward and back in such a manner that one rear wheel touched every point of the surface. The surface was then dampened if necessary and rolled crosswise in the same manner. As the work progressed the traction engines gradually took up the work of rolling as they brought the material to the fill, and finally superseded the roller entirely. The slow progress resulted in the fill getting a thorough soaking from rains every third or fourth layer, and this helped materially toward extreme solidification of the fill. At times the fill was so solid that a small boulder lying on it would be crushed by the traction engine passing over it.

Progress Made on Embankment. Small boulders were permitted in the fill only if they could be rolled out of sight in the layer being placed, which was about 3½ inches after solidification. All others were kept out. In scheme No. 1 the excavator dropped the excavated material into a hopper having a sloping grating of 50-pound rails on top. The earth dropped through into a wagon, and the boulders ran off into the cut. In scheme No. 2 the boulders were thrown to one side or hauled to the crusher. In scheme No. 3, earth and boulders were dumped on the fill and the boulders either thrown over the bank to be handled later or hauled to the crusher. While working scheme one, 125 yards of embankment per working of shift were placed under scheme two, 122 yards and under scheme three, 108 yards per working shift.

In all about 10,000 cubic yards of stone were hauled to the crusher from the fill and borrow pits.

Settlement of Embankment. Measurements taken in April, 1911, six months after the completion of the rolled embankment, showed a settlement of ¼ inch. The aqueduct was constructed on this embankment in September and October, 1911, and up to date has shown no signs of settlement.

After considerable difficulty was experienced in the excavation of a deep cut the last concrete arch on this contract was placed in 1912, leaving considerable refill to be made in the following season.

CHAPTER XI

MOODNA, HUDSON, BREAKNECK AND BULL HILL TUNNELS OF THE HUDSON RIVER DIVISION

Contract 20

General Description of Contract 20 (Moodna Siphon). This contract comprises work between the long stretch of cut-and-cover in the Newburgh Division and the Hudson River. It is a tunnel about 25,000 feet long constructed from seven shafts, 371 to 586 feet deep. The only waterway shaft is No. 1, connecting with the cut-and-cover. Shaft 7 will be an access shaft, and all the others, except No. 1, will be refilled. The Moodna tunnel is really a portion of one siphon known as the Moodna-Hudson-Breakneck Siphon, constructed from ten shafts. The shaft east of the Hudson is to be used as a drainage shaft for the entire siphon. About two-thirds of the tunnel penetrates Hudson River shale, and the remainder granite, similar to that of Storm King and Breakneck. Numerous borings were made along the center line, principally to determine the preglacial gorge of the Moodna, which was found to be very wide, reaching an elevation of about −50 and determining the depth of the tunnel at about −200.

Contract Prices. The contract was let in June, 1909, to the Mason & Hanger Co. The total contract price was $3,492,511. Some of the bid prices are as follows:

Construction shaft in earth per foot	$180 to $200
Construction shaft in rock (granite) per foot	$250
" " (shale) per foot	200
Excavation of tunnel in granite per cu.yd	6.75
Excavation of tunnel in shale per cu.yd	5.40
Rock excavation in downtake shaft per yd	15.00
Concrete masonry in shafts per cu.yd	8.00
" " in tunnel per cu.yd	5.25
Portland cement, per bbl	1.20
Forms for lining tunnel, per foot	4.00

On the basis of contract quantities and prices the 337 feet of cut-and-cover aqueduct of this contract will cost the city $56.87

per foot; 25,130 feet of pressure tunnel, including shafts, $138.10 per foot. Subdivisions of the latter item are as follows:

Cost per Lineal Foot.					
Construction Shaft.		Waterway Shaft.		Access Shaft. Rock.	Tunnel.
Earth.	Rock.	Earth.	Rock.		
$203.98	$221.79	$246.71	$201.50	$330.51	$104.48

Shaft Sinking (General). Shafts 1 to 5 were sunk by the Dravo Contracting Company, who built a plant for this purpose at Moodna Creek, consisting of four 100-H.P. boilers and a compressor capacity of about 2500 cubic feet per minute with 6-inch air lines connecting Shafts 2, 3, 4, and 4-inch lines to 1 and 5. Shafts 6 and 7 were sunk by Harry & McNiel, using a steam plant at Shaft 6 with a compressor capacity of about 1400 cubic feet per minute. One hundred and forty-five feet of earth was found to cover the rock at the downtake shaft, this being the deepest shaft in earth north of the city line. The material, however, proved to be a very tight glacial drift, which was readily excavated in stretches of about 40 feet and then lined with concrete.

Shaft 2 in Earth (Caisson for). More trouble was experienced in reaching rock at Shaft 2. An attempt was made to sink a concrete caisson 3 feet thick, 21 feet inside diameter, but at a depth of 49 feet the friction became so great that further progress with the caisson became impracticable; the remaining 52 feet of the shaft in earth was timbered in the usual manner without any particular trouble. It is the usual experience that an open caisson can hardly be sunk below a depth of 50 feet without being loaded very heavily. This caisson was loaded with pig iron and lubricated by forcing water around the outside through pipes. In addition dynamite was used to lessen the friction, all of which was of no avail beyond a depth of 49 feet. Pneumatic caissons are frequently sunk to much lower depths, but they are very heavy, being solidly filled about the working chamber with concrete or sand, and, in addition, heavily loaded with pig iron. The air escaping around the cutting edge probably reduces the friction, and the drawing down of the air in the chamber at critical times furnishes a ready means of pounding down the caisson. Even then a frictional resistance up to 1500 pounds to a square foot is sometimes reached.

Progress in Shaft Sinking. The shafts were sunk without special incident by the usual methods. At Shaft 1 a shaft-sinking record was made of 174 feet in one estimate month. This was excavation in Hudson River shale with no timbering. The shaft was circular and was sunk by the same organization and with the same method as was used on Shaft 1 of the Rondout siphon, except that a little longer advance was made per shot. The following table gives the time consumed and speed made in sinking the various shafts on this contract:

	Excavation. Feet.	Months.	Average. Feet.	Best Monthly Progress.	
				Excavation. Feet.	Timbering. Feet.
Shaft 1	586	8	73	166	0
Shaft 2	487	7	70	86	79
Shaft 3	342	7	49	60	30
Shaft 4	403	5	80	89	88
Shaft 5	432	6	72	82	72
Shaft 6	537	7	79	86	79
Shaft 7	373	7	54	75	0

The inflow of water into the shafts varied from 4 to 45 gallons per minute, except at Shaft 3, where the flow reached 100 gallons per minute. Work of last two columns was done in the same month.

Permanent Shaft Equipment. After the shafts reached grade and a short stretch of tunnel on each side was excavated by bucket, the shaft-sinking equipments and power houses were removed, and the permanent plant installed. Over each shaft a wooden head frame 44 feet high was erected and a Flory hoist with 60-inch drums and 14″×18″ cylinders, operating two balanced self-dumping cages, was installed. These cages were made by the Eagle Iron Works, Terre Haute, Ind. They automatically dumped the low muck cars directly into the muck bins, the bottom of the cage sliding forward on rollers and tilting by means of a cam attached to the head frame. From the muck bins the excavated material was discharged into side-dumping cars and hauled to the spoil banks.

Power Plants. Two power plants were installed to supply compressed air to the shafts. In the main plant, near Shaft 3, were installed four Sullivan compound straight-line compressors with Corliss engines, having a total air capacity of about 10,000 cubic feet per minute, and 4 Heine boilers of 300 H.P. each. An 8-inch pipe line carried the air to Shafts 1, 2, 3, 4 and 5. The smaller plant for

Shafts 6 and 7 was located near the West Shore Railroad at Cornwall and was equipped with two cross-compound Ingersoll-Rand compressors with a combined capacity of 5000 cubic feet of free air per minute and three 250 H.P. water-tube boilers.

Progress Made in Driving Tunnel. The tunnel was excavated by the ordinary top-heading and bench method, no attempt being made to secure great speed, but every effort was put forth to secure economy in driving. While running with full force, the average progress of excavation for completed tunnel was between 200 to 250 feet per month with a maximum of about 322 feet. During the month of November, 1910, when tunnel progress was at a maximum, 3204 feet of completed tunnel was excavated in 13 headings at an average progress of 246 foot per heading, maximum 304 feet, and minimum 171.

The organization for Shafts 6 and 7 for both excavation and concrete was furnished by Mr. Mundy, whose progress in excavation of granite tunnel was remarkable, averaging for some months about 300 feet.

Tunneling with One Drilling Shift. Two general methods of excavation were used. In shale, at shafts with two headings, the heading was drilled and shot and entirely mucked out, the drillers not returning until this was done. Only one drilling gang and two mucking gangs were employed in each heading. By this arrangement the drillers always worked in headings clear of muck and smoke, the muckers having their shifts arranged so as to suffer little delay from the shooting and from smoke. By this method a daily advance of from 6½ feet to 8½ feet per round was made, and the labor charges were cut down to the lowest, but the progress was only about one-half as much as made with two drilling shifts and three mucking shifts in the Wallkill and Rondout pressure tunnels in similar rock. It is a question whether the overhead charges by this method did not more than make up for the decreased labor cost. Overhead charges in tunnel driving are nearly fixed, so that lessened progress means a less yardage per month to charge it to.

Tunneling with Two Drilling Shifts. Another method, and probably the most economical for shale excavation, by which a very good progress was obtained, is as follows: Two drilling gangs were worked per day at each shaft between 8 A.M. and 4 P.M. and 8 P.M. and 4 A.M., so as to drill two rounds per day in each heading. By allowing four hours between drilling shifts opportunity was given to clear the heading of the muck before the arrival of the next drilling gang. Three shifts of muckers were employed in each heading.

Tunneling Method in Granite. For tunneling in granite, where it took sixteen hours to drill 24 heading holes with four 3½-inch tripod drills on columns, two methods were used: First, three drilling shifts and three mucking shifts in the two headings were alternated so that drillers always set up in a clear heading. By the second method, three shifts of drillers and three shifts of muckers worked in each heading, but lost two to four hours per day on account of shooting; the cut often requiring loading three times before it was satisfactorily blasted. By the first method the cost per yard excavated was considered to be less. About 4½ pounds of 75 per cent dynamite was used per cubic yard excavated, and about 208 feet of holes was drilled for a 7½ foot advance, equal to 35 cubic yards excavated, which was sought for every day.

Character of Rock in Moodna Tunnel. The rocks penetrated by the Moonda tunnel gave little trouble except at two spots, one in the shale directly under the buried Moodna Valley where considerable water was encountered, and the other where the shale was weakened by the over-thrusting of Storm King Mountain upon it. Here some structural steel roof support was placed at the contact. In general the tunnels were dry and yielded little water. A feature was the good progress made at Shaft 6 in the Storm King granite.

Concreting Invert. After the main excavation was completed the tunnels were trimmed and the bottom muck excavated to solid ledge. A 5-foot invert strip was then placed in the same way as that described under Wallkill and Rondout tunnels, except that at some shafts the invert was placed by working away from instead of toward the shafts as in the other two tunnels. This meant that the track had to be placed on the newly laid invert. The advantage of this method is that the laying of a track is saved together with some saving in cleaning up bottom.

Concrete Plants at Shafts 2 and 3. Blaw steel forms for side walls and arch were installed similar to those used in the Wallkill tunnel, and the method of "trailing" forms followed, using inclines as before described. At Shafts 2 and 3 a Lakewood mixer at the surface discharged its concrete directly into a car placed on the shaft cage, which was stopped a few feet below the landing platform. This has the advantage of eliminating a few men required to push the cars off and on the cages, as in the method of mixing to one side practiced on the Rondout and Wallkill tunnels; but it also has the disadvantage of tying up the cages for other uses while the mixer is discharging concrete, and also creates more or less of a nuisance, due to spilled concrete.

Sand and Gravel Pit for Shafts 2 and 3. Sand and gravel for Shafts 2 and 3 were obtained from a gravel bank near Moodna Creek, where the material was excavated by stiff-legged derricks operating orange-peel buckets. The material was dumped into an elevated traveling bin, screened and discharged into dump cars which were hauled over a narrow-gauge track by dinky engines directly to Shaft 2 and by a cableway to Shaft 3. The plant at the sand and gravel pit was steam operated by two 40 H.P. boilers, one Mundy and one Lidgerwood hoist and three other engines.

Electric Locomotives for Concreting Tunnel. Owing to the difficulty of transportation to several of the shafts of the Moodna tunnel, all the concreting was done from three shafts, necessitating rather long hauls in the tunnel which, however, caused little delay, the 3- and 5-ton electric locomotives readily hauling trains of from four to six cars.

Arrangement of Forms in Tunnel. The mixer at Shaft 2 supplied concrete for three sets of 45-foot arch and side-wall forms between Shafts 1 and 3. In a similar manner the plant at Shaft 3 was used to supply forms between Shafts 3 and 5, and that at 6 between 5 and 7. The total number of forms operated for the entire tunnel was nine sections of 45 feet for side wall and arch. Later, to increase the progress between Shafts 3 and 5, an additional concrete mixer was installed at Shaft 5, for the use of the Shaft 3 organization. Between Shafts 1 and 3, 45-foot forms were used at first. Then the form near Shaft 3 and working toward Shaft 2 was increased in length by the addition of 15 feet. It was found to require little if any more time to fill this than the 45-foot forms. Later when the closure had been made by the form working from Shaft 1 toward Shaft 2, it was taken down and reerected as an addition to the 60-foot form, making one 105 feet long.

Plant with Mixer at Bottom. The most interesting and original plant was that installed at Shaft 6. The tunnel muck from the spoil bank (Storm King granite) was crushed in a No. 3 and No. 8 McCully crusher and elevated to bins. The smaller crusher discharged into sand rolls which with the regular crusher dust furnished sufficient fine material to enable a 45-foot section, and later a 60-foot section, of tunnel to be daily concreted. From this it appears that from 10 to 15 cubic yards of sand were crushed in the rolls in 8 hours. The tunnel spoil was loaded by a steam shovel in 4 cubic-yard side-dumping cars which were hauled to the foot of an incline by mules and then up the incline to the crusher by a cable. The 1-yard Lakewood mixer operated by an electric motor was set up at the bottom of the shaft about 4 feet above the floor of the tunnel. At first it was fed with sand and stone by an 8-inch pipe, but this gave a great deal of trouble, because of frequent clogging, and it wore out rapidly.

Use of Bins in Shaft. Later, one cage compartment was divided into two bins, one for sand and one for stone, this being subdivided horizontally into compartments 70 feet high, the material flowing from one bin to the one lower through a 12-inch hole. This worked satisfactorily, the shaft bins being fed from the surface bin, which was fed by the crushing plant at the top. The shaft bins were not kept full. The sand and stone were fed to the wooden chutes on signal from the bottom. The material entering at the top fell to the bottom of the first compartment, where a sort of conical hopper of the material itself was formed which received the impact of the falling stone or sand. This prevented the wearing of the bottom. The sides did not wear, because in the 70- or 80-foot drop the stone fell vertically and its first contact was the hopper of material which had formed around the hole in the floor. The charging hopper of the mixer was placed underneath the chute gates of the sand and stone bins in the shaft and the mixer discharged into the cars running on the tracks under the mixer. These cars held a 5-bag batch and were hauled in a train of four cars by a 3-ton electric trolley locomotive.

With this plant rapid and economical work was done. At times a 45-foot form was filled in fourteen hours. Cement was brought to the mixer, 25 bags at a time, on the single cage which was kept in operation in the shaft.

The force employed while concreting at Shaft 6 was about as follows:

	12 P.M. to 8 A.M.	8 A.M. to 4 P.M.	4 P.M. to 12 P.M.
Foreman	4	3	2
Hoist runner	1	1	1
Fireman	1	2	1
Signalman	2	2	1
Laborer	24	41	24
Carpenter	2	2	
Electrician	1	1	1
Pumpman	1	2	1
Motorman	2	2	2
Poleman	2	2	2
Enginemen		2	
Cranesman		1	
Blacksmith		1	
Blacksmith helper		1	
Mechanic		1	

Total about 150 men for three shifts, including top force at crushing plant.

Comparison of Top and Bottom Shaft Concrete Plants. By comparison it would appear that the Wallkill progress was somewhat better where latterly a 60-foot section was filled in two shifts, using at the forms 23 men on one shift and 17 on the other. It would also appear that the top concrete plant as arranged on the Wallkill and Rondout tunnels has certain advantages: First, all the work is at the top, the machinery being open to inspection and repair by daylight, most of the mixing being also done then; second, the expense of building bins and taking them out of the shaft is saved; and third, both cages are kept in operation, and no cement need be sent separately to the bottom. Locating the mixer in the tunnel saves men used to place cars in cages and to push them off at the bottom to make up trains. This is probably offset by the two men necessary to handle the cement off and on the cages. With either plant the concrete can be mixed faster than is practicable to take the concrete at the forms. The type to be used is the one most convenient for the place in question, but the consensus of opinion is that the top concrete plant is preferable for deep shafts.

Hudson Siphon—Contract 90.

Urgency of Work. The two shafts known as the Hudson River test shafts and later as the downtake and drainage shafts of the Hudson siphon reached tunnel grade late in 1910, this work being executed, as before explained, directly by the forces of the Board of Water Supply. At this time all contracts from Ashokan Dam to the city line had been let and were well under way, particularly those contracts of the Northern Aqueduct department above Croton Lake. The long-predicted shortage of water caused by overdraft on the Croton watershed was impending, and it seemed necessary to make every effort to deliver the Catskill water to Croton Lake to enable the Croton aqueduct to continue to supply the city with its maximum flow. The condition of the contracts of the Northern Aqueduct department was such that it seemed likely that water could be delivered to Croton Lake late in 1913 in case the tunnel under the Hudson was completed by this time.

Time Limits of Contract. Contract 90 contained requirements very unusual in public contracts. The main feature was the high rates of progress demanded and very specifically laid down in the contract. This contract, for which bids were opened

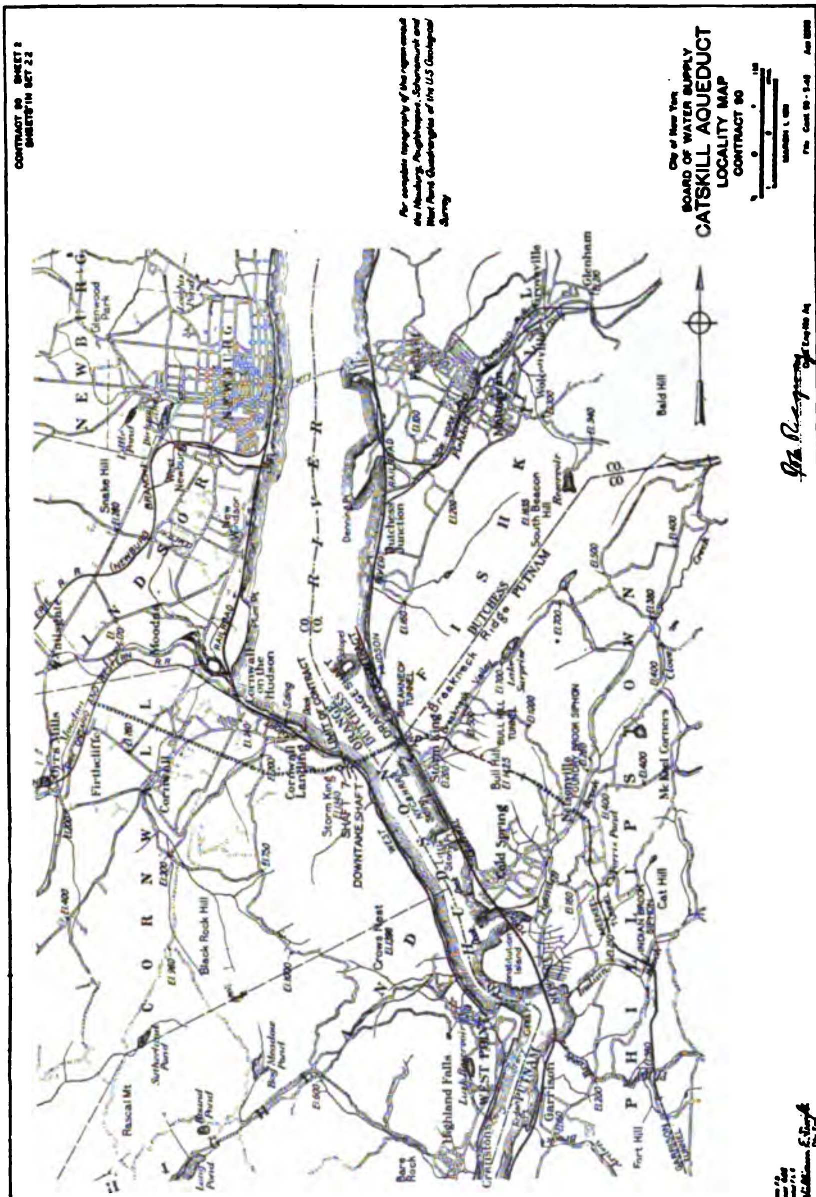


PLATE 135.—Contract 90. Locality Map Showing Aqueduct at Hudson River Crossing and Adjoining Stretches.

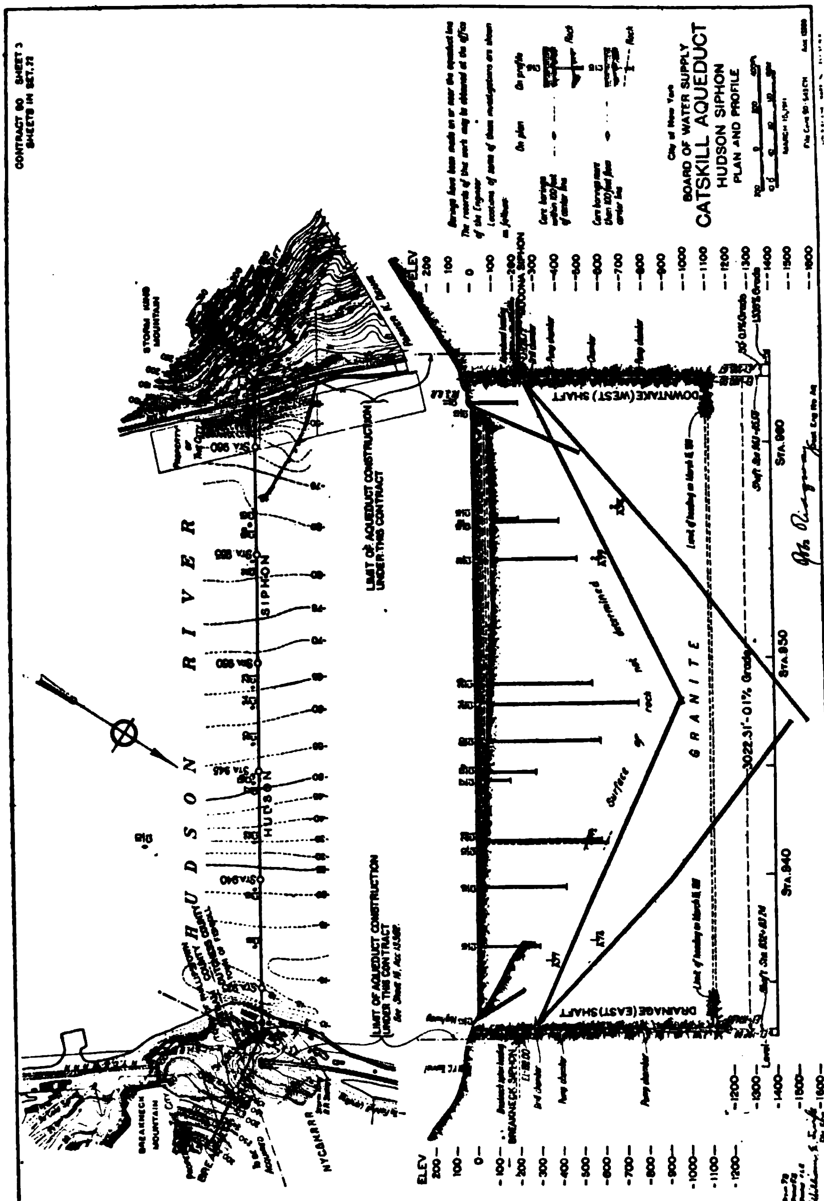


PLATE 136.—Contract 90. Profile and Plan of Hudson Siphon Showing Vertical and Inclined Core Holes, etc.

May 23, 1911, provides that by April 1, 1913, the work should be far enough along to permit the use of the siphon as a part of the aqueduct. October 13, 1913, is mentioned for the completion of the entire work.

Required Progress. In the light of the experience gained on the other siphons, the following rates of progress were thought to be feasible and were specified for Contract 90:

ESTIMATED NECESSARY AVERAGE RATES OF PROGRESS FOR MAIN OPERATIONS

Operation.	Rate per Calendar Month.
Excavation of Hudson siphon tunnel	200 linear feet of full section or equivalent in each heading.
Lining of Hudson siphon tunnel invert, including necessary trimming and cleaning of invert	900 linear feet in each heading.
Lining Hudson siphon tunnel above invert	625 linear feet in one or each heading, as necessary.
Lining portion of downtake shaft below elevation −233, including removal of support	210 linear feet.
Lining drainage shaft below elevation −197, including removal of support	170 linear feet.
Placing outer and inner linings of drainage shaft above elevation −175, including steel interlining, steel anchor ring and blow-off nozzle, but not placing steel frame, cover and anchor bolts; removal of support included	60 linear feet.

The above rates include all delays due to periods of preparation between different kinds of work, and rates considerably higher will be necessary for most of the time to attain these average rates. The contract also specifies that delays and accidents will not relieve the contractor from the necessity of accomplishing the work on or before April 1, 1913. Also that in default of completing the work by the above date the sum of $200 per day is to be paid to the City as liquidated damages. It was recognized that with the city plant at hand to be turned over to the contractor the progress specified could not be made.

Requirements for Plant. The contract specifically names the plant to be installed in addition to that already on hand. This is a very unusual feature and ordinarily not advisable, as it is pretty certain to increase the contract cost and, in case the conditions do not turn out as expected, it is liable to leave the City in an uncertain legal position, for if the specified plant should prove to be inadequate and not fitted for the work the contractor can claim damages or relief from the guarantees of the contract, or at best the contract may be modified by mutual agreement, in which case the cost is very liable to be largely increased and the time extended. However, it was felt that sufficient experience and information had been

PLATE 137.—View from West Point of Hudson River at Storm King and Breakneck, where Catskill Aqueduct Crosses 1100 Feet Below Surface of River.

gained on the other contracts to justify this course and that it was better to have a surplus of plant on hand to meet any needs likely to arise than to wait, in the usual manner, for developments and the gradual installation of new plant to meet them.

Required Pumping Equipment. The principal source of delay in a contract of this character is, of course, water, which might be expected in considerable quantities and under a very high head. Therefore, under Items 9 and 10, additional construction pumping plant and additional electrically driven centrifugal pumping units are specified and required to be immediately installed sufficient to cope with any flow to be expected, as follows:

a. Within seventy days furnish at either shaft one additional Jeanesville pump identical with those installed by the city (2-cylinder 16″×7″×18″).

b. Within forty-five days install at the foot of each shaft two Jeanesville pumps so as to complete a plant in each shaft capable of lifting 800 gallons per minute to the surface.

c. Within ninety days install six additional Jeanesville pumps, one to be placed in each pump chamber in both shafts so as to complete a plant in each shaft capable of lifting 1200 gallons per minute to top.

d. Within sixty days install additional boiler capacity at each shaft to afford sufficient power for the operation of the nine Jeanesville pumps.

e. Within ninety days install in each shaft two electrically driven centrifugal pumps to discharge 500 gallons per minute to the top of the shaft together with a power plant or power lines sufficient to operate one pump.

Under Item 10, additional electrically driven pumps could be ordered to be supplied by the contractor within seventy-five days.

To provide against delays in concreting the contractor was paid in advance for 180 feet of tunnel and shaft forms.

Organization Required. The contract further provided that the work should be begun within twenty-four hours after service of notice by the board. Also that within twenty calendar days after notice his organization and equipment should be sufficient to at least maintain the required rates of progress. The intent was to award the contract to a party who could transfer almost immediately a complete tunnel organization capable of prosecuting the work at a very high rate of speed.

Award of Contract. The contract was awarded June, 1911, to T. A. Gillespie Company, although they were the third lowest bid-

BOARD OF WATER SUPPLY OF THE CITY OF NEW YORK

Contract 90, for the Completion of the Hudson Siphon, Catskill Aqueduct

Canvass of Bids opened May 23, 1911, at 11 A.M.

Item	Description.	Unit.	Quantity.	The T. A. Gillespie Co., 50 Church St., New York	
				Price.	Amount.
1	Removing shaft support	Lin.ft. of sh.	2,160	10.00	21,600.00
2	Scaling in shafts	Cu.yd. (loose)	1,000	10.00	10,000.00
3	Refilling above closure in downtake shaft	Lin.ft. of sh.	50	25.00	1,250.00
4	Excavation of tunnels	Cubic yard	28,000	17.50	490,000.00
5	Additional trimming in shafts and tunnels	Square yard	500	6.00	3,000.00
6	Furnishing structural steel roof support	Pound	400,000	.03	12,000.00
7	Erecting structural steel roof support	"	500,000	.02	10,000.00
8	Temporary timbering	M ft. B.M.	50	100.00	5,000.00
9	Additional construction pumping plant	Lump sum	....	....	140,000.00
10	" electrically driven centrifugal pumping units	Pumping unit	2	15,000.00	30,000.00
11	Pumping from shafts and tunnels during construction	Mil. ft. gal.	600,000	.30	180,000.00
12	Drainage channels for shafts and tunnels	Lin. ft. sh. & tu.	5,440	2.00	10,880.00
13	Furnishing forms for lining downtake shaft	Lin.ft. of form	20	100.00	2,000.00
14	" " drainage shaft	"	60	100.00	6,000.00
15	" " tunnels	"	100	100.00	10,000.00
16	Special forms for junctions, etc.	Lump sum	....	....	5,000.00
17	Using forms in downtake shaft	Lin.ft. of sh.	857	10.00	8,570.00
18	" " drainage shaft	"	1,084	10.00	10,840.00
19	" " tunnels	Lin. ft. of tun.	3,012	5.00	15,060.00
20	Concrete masonry in shafts	Cubic yard	11,500	12.00	138,000.00
21	Concrete masonry in tunnels	"	15,000	13.00	195,000.00
22	Excess concrete masonry in tunnels	"	500	3.00	1,500.00
23	Brick masonry in shafts and tunnels	"	100	10.00	1,000.00
24	Dry packing	"	1,200	3.00	3,600.00
25	Furnishing and erecting steel castings	Pound	100,000	.08	8,000.00

26	Steel interlining in drainage shaft	Pound	185,000	.08	14,800.00
27	Drilling 1½-inch or smaller holes in rock or masonry	Linear foot	300	1.00	300.00
28	" 1¾-inch to 2½-inch holes in rock or masonry	"	600	1.50	900.00
29	Core borings	"	2,000	10.00	20,000.00
30	Steel pipe for grouting, etc	"	4,000	.30	1,200.00
31	Plant and equipment for grouting	Lump sum	....	....	5,000.00
32	Grouting rings	Pound	100,000	.10	10,000.00
33	Making connections of grouting machines to grout pipes	Connection	500	3.00	1,500.00
34	Setting grouting rings and pads	Setting	100	25.00	2,500.00
35	Sand for grout	Ton	600	3.00	1,800.00
36	Mixing and placing grout	Cubic yard	1,200	9.00	10,800.00
37	Hydrostatic tests	Month	5	5,000.00	25,000.00
38	Excavation in open cut	Cubic yard	5,000	5.00	25,000.00
39	Refilling and embanking	"	1,300	1.50	1,950.00
40	Timber and lumber	M. ft. B.M.	40	60.00	2,400.00
41	Concrete masonry in open cut	Cubic yard	1,500	15.00	22,500.00
42	Reinforced concrete not in tunnel	"	50	20.00	1,000.00
43	Portland cement	Barrel	63,000	1.70	107,100.00
44	Steel for reinforcing concrete	Pound	28,000	.06	1,680.00
45	Miscellaneous cast iron, wrought iron and steel	"	165,000	.10	16,500.00
46	Galvanizing	"	2,000	.03	60.00
47	Caring for and setting metal-work furnished by the city	"	500,000	.07	35,000.00
48	Cast-iron pipe and special pipe castings	Ton	3	100.00	300.00
49	Miscellaneous gates and valves	Gate or valve	5	100.00	500.00
50	Bronze pipe and miscellaneous bronze	Pound	16,000	1.00	16,000.00
51	Vitrified pipe 12-inch and smaller	Linear foot	100	1.00	100.00
52	Dry rubble masonry and paving	Cubic yard	100	4.00	400.00
53	Rubble masonry and paving in mortar	"	100	5.00	500.00
54	Crushed stone and gravel	"	100	3.00	300.00
55	Reinforced concrete ladders	Linear foot	63	10.00	630.00
56	Cleaning up	Lump sum	....	....	5,000.00
					$1,649,020.00

Bond required: $350,000. Time: April 1, 1913.

der. The lower bidders were not equipped with a tunnel organization which could be transferred to this work, although the competency of the second bidder, Winston & Co., could not be questioned for any ordinary contract. The Rondout siphon under Contract 12 was so far along toward completion that a large part of the experienced force there could be transferred to the Hudson siphon. The general superintendent, R. J. Gillespie, and his assistants thereafter supervised both contracts. The total of the contract was $1,649,000, but this sum will probably not be paid out, as the pumping is certain to fall far short of the estimated amount, the other items being also liberally estimated to provide for contingencies not likely to be met.

The designs of Contract 90 are very interesting and show several unusual features, in some respects improvements on previous contracts, this being the last siphon contract prepared, although the City Aqueduct contracts were awarded later.

Improved Cross-section for Excavation. Following the advice of the engineers engaged on the construction of the previous siphons, although the waterway is circular (14 feet in diameter), the excavation lines were fixed so as to give a flat bottom about 10 feet wide, to avoid delays and difficulties experienced in excavating a circular tunnel. In order to get room for the tracks it was necessary heretofore to leave considerable muck in the bottom, particularly at the double-tracked stretches and cross-overs, and it was also found that considerable trimming remained to be done in the bottom, previous to concreting. Because of the horseshoe section of the Hudson siphon the bottom was excavated to subgrade in the first operation and the tracks laid directly on the rock floor, leaving very little muck to be taken out before concreting.

Water-bearing Seam at East Shaft. Shortly before the letting of Contract 90, while the City forces were driving the tunnel westerly from the East shaft, at a distance of 275 feet from the shaft a water-bearing seam was opened by the shooting of the heading. At the time no pumping equipment was in place at the bottom of the shaft, so that the tunnel was flooded, causing the report to spread that the Hudson River had been broken into and that the tunnel was lost. The water before it could rise in the shaft was pumped down by several small pumps and the fissure through which the water was issuing was blanketed with concrete while the water (about 150 gallons per minute) was allowed to flow through a 4-inch pipe. The concrete was rafted through the tunnel to the bench. After

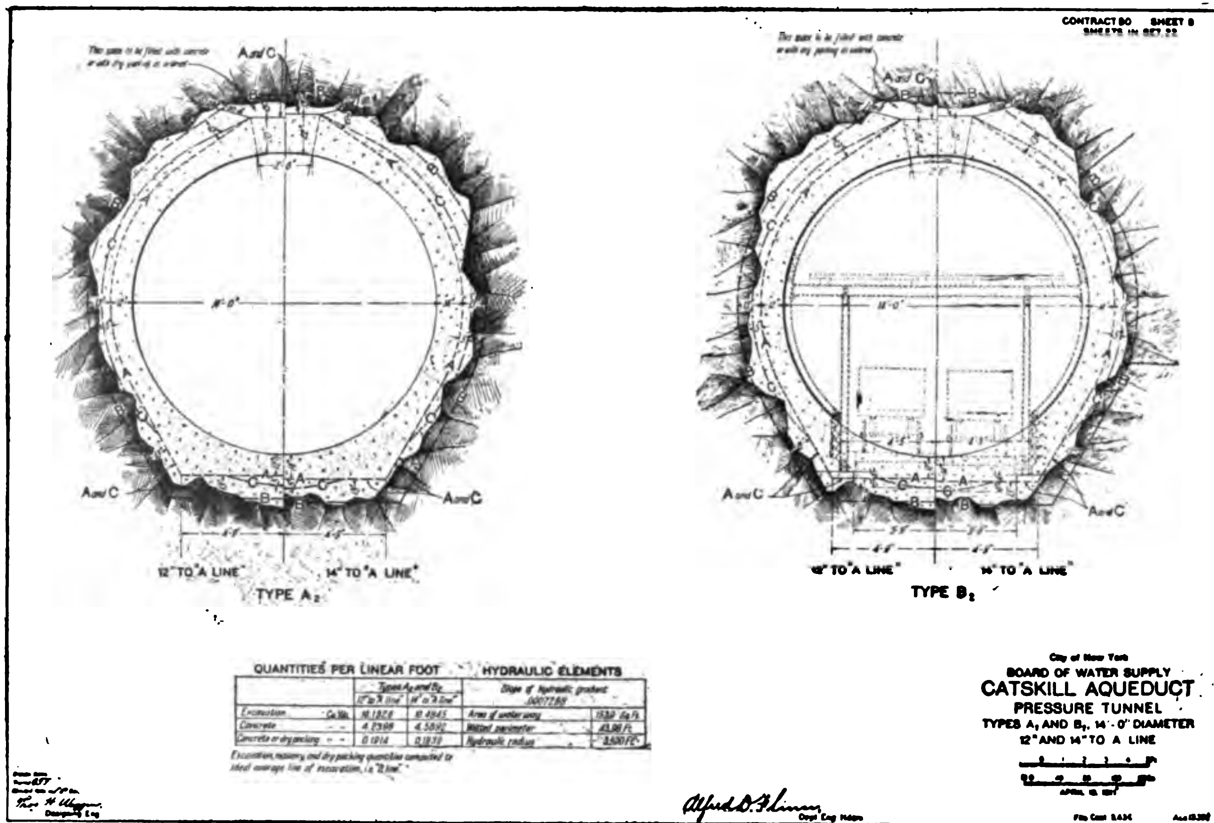


PLATE 138.—Contract 90. Typical Cross-sections of Hudson Pressure Tunnel. Different for others in use of flat bottom for excavation. The latest section used for pressure tunnels on Catskill aqueduct.

the concrete in the heading face had set, the water rose in the 4-inch pipe 386 feet to the pump chamber at elevation −788.

Beginning of Work by T. A. Gillespie Company. After the bench had been excavated the work was turned over to the T. A. Gillespie Company on June 22, 1911. While the work of tunneling was being vigorously prosecuted at the West shaft and additional plant was installed at both sides of the river, preparations were made to take care of a large volume of water at the water-bearing seam encountered near the East shaft. A very thick concrete bulkhead (see Plate 139) with steel door was built about 200 feet from the shaft to safeguard the tunnel against a repetition of the flooding. Between the bulkhead and the shaft the pumping plant was installed. Meanwhile a diamond-drill hole was driven into the face of the heading to explore the ground ahead. Little water was struck, however, 513 feet of hole yielding only 14 gallons per minute, with sound core.

Grouting with Pump. Preparations were next made to grout off the water-bearing seam. Holes were drilled until the water was struck, or to a depth of 20 feet, and plugged with pipes and valves. A reinforced concrete bulkhead was then placed to fill the entire heading, the pipes extending through. This was done for the purpose of preventing the pressure of grout from blowing out the face of the heading.

The contractor found that he could not secure an air compressor to give the required pressures for grouting the heading, where the gauges in the pipes indicated a water pressure of about 470 pounds per square inch. It was then resolved to try grouting with a pump. An air-driven Cameron pump, $10'' \times 3\frac{1}{2}'' \times 13''$ was connected with a Canniff grout tank partly filled with neat cement grout, which placed this grout under a hydraulic pressure of 1000 pounds per square inch, driving the grout into the rock through pipes in the bulkhead which were connected up one by one. This grouting was found to be very successful, as when excavation was resumed on October 12th (three days after grouting), the water-bearing seam was encountered and although previously under a high head yielded only a small drip. The seam consisting of only a few inches of ground rock was found to be well filled with grout; later when the bench was blown out about 20–30 gallons flowed steadily from the lower portion of seam. This was the first instance on the aqueduct where high pressure grouting was done directly by a pump, but the result indicated that this method has several advantages over air injection. Higher pressures can readily be obtained and no air is entrained with the grout. The pulsating of the pump probably aids

Plate 139.—Contract 90. Concrete Bulkhead at East Shaft Hudson Siphon. Its purpose was to safeguard shaft in case of sudden inflow of water while excavating heading. Designed to withstand head of 1100 feet. It was never necessary to close door.

in forcing the grout in, overcoming the friction of the grout in entering narrow seams.

Electric Power Plant. Although the work of tunneling was vigorously carried on, by far the largest work for the first six months was the installation of the plant required by the contract. In addition to the Jeanesville pumps specified, two Worthington 8-stage electrically driven centrifugal pumps of 500 gallons per minute capacity under 1160 feet head were installed at each shaft. The main power plant for supplying current was installed at the East shaft and consisted of a kilowatt Curtiss steam turbine generator, a cable being laid under the river to supply the pump at the west side, current being stepped down from 6000 to 450 volts.

Compressed-air Plant. Compressed air at the west shaft was supplied from the City plant there, which was considerably enlarged by compressors and boilers brought down from the power plant at High Falls (Contract 12), consisting of two Ingersoll-Rand 2-stage 2400-foot air compressors operated by a 350-H.P. Heine boiler. Four 100-H.P. Nagle locomotive-type boilers were installed as an emergency outfit to operate the Jeansville pumps.

Tunnel Progress at West Shaft. At the west shaft little time was lost in getting started, and good progress was made despite the treacherous nature of the Storm King granite penetrated. An average progress of 269 feet per month was made, maximum 300 feet and minimum 238 feet. "Popping" rock gave considerable trouble at times, resulting in failure to obtain the usual daily progress of two rounds in the heading. At the worst stretches, a light steel roof support was erected, a total of 646 feet being placed in thirteen places.

Popping Rock. The phenomenon of "popping rock" was first observed in the lower portion of the west shaft, where steel lagging was placed to protect the men. The rock appeared to be under considerable stress and peeled off in layers for three to four weeks and continued to scale and pop, although apparently perfectly sound when first exposed. It was confined to the west side mostly, in a greenish granite, never in the pink varieties or in the diorite veins. Where encountered the rock has been very dry; for 300 feet of shaft and 1600 feet of tunnel only 5 gallons per minute of water had been intercepted. The rupture occurred on the north side wall and in the roof almost exclusively. The fragments dislodged were usually thin slabs $\frac{1}{16}$ inch to 2 inches thick, which did not always fly away from the mass and could be noted clinging to the walls. After removing these, the rock may sound

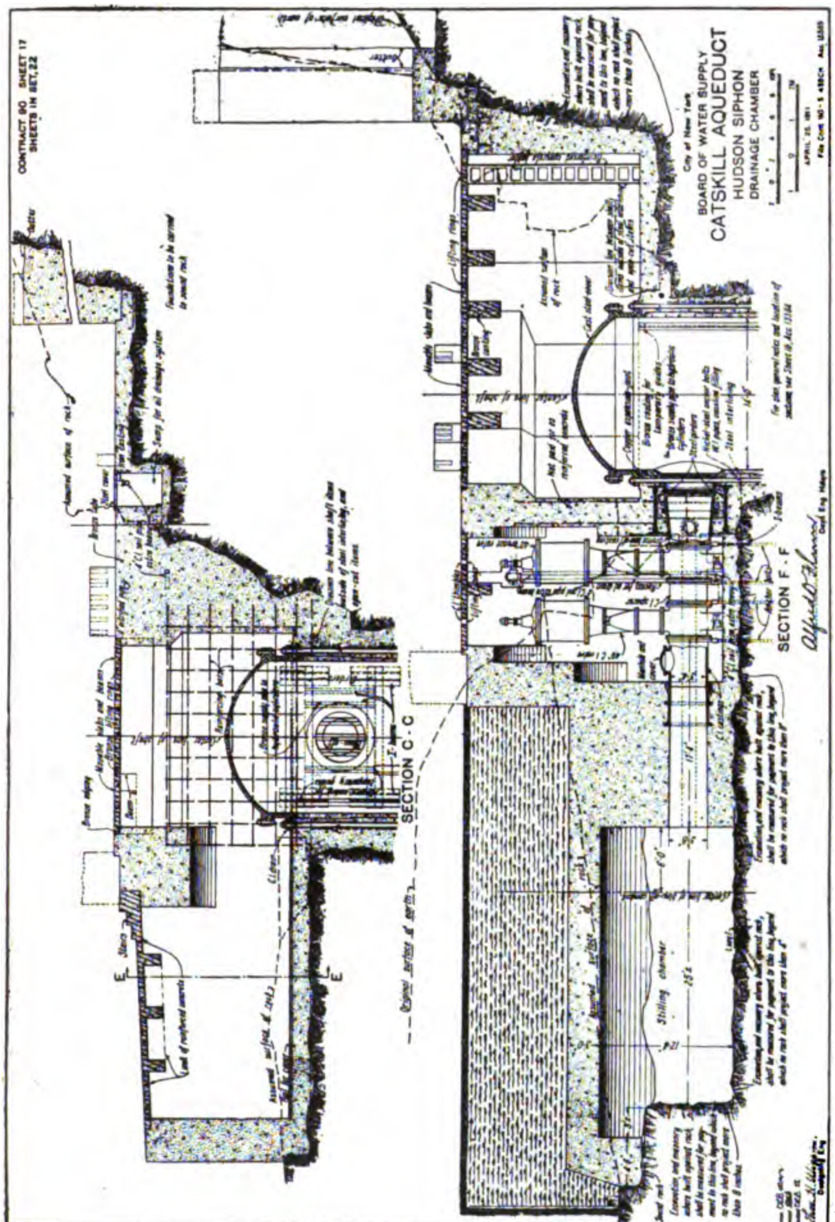


PLATE 140.—Cross-section of Drainage Chamber at Uptake Shaft, Hudson Siphon. Shows cast-steel cover and blow-off into river.

PLATE 141.—Proposed Superstructure at East Shaft of Hudson Crossing, Breakneck Mountain in Background. Blow-off and stilling chamber in foreground,

solid under the hammer, yet in a day or two loose pieces would be found at the point marked. Some of the rock in the Rondout tunnel also exhibited this "popping" feature, notably in the Esopus shale and the Onondaga limestone. In the former the rock broke loose into conchoidal fragments; in the latter in flat slabs. In both the Hudson and the Rondout tunnels the phenomenon gave great annoyance to the engineers, who would find their scales and line plugs under a mass of rock fragments, after carefully selecting what they thought to be the most solid places.

Tunneling Method. From the west shaft two rounds per day were shot. Two drilling shifts were employed between 8 A.M. and 4 P.M. and 8 P.M. and 4 A.M. Four drills were used in the heading, mounted in columns, two on tripods for the bench. Each drilling shift, before leaving, shot the round drilled by them. Three mucking shifts were employed to clear the tunnel. The flat bottom proved to be a great help, enabling the tunnel to be cleared down to subgrade, the track being placed directly on the bottom.

Single Cage in Shafts. Only one cage could be installed in the 1100-foot shafts owing to the arrangement of shaft timbers. They were at first operated unbalanced by the Mundy engines, which gave considerable trouble. Later, Lambert hoists from the Rondout shafts practically superseded the Mundy hoists, working excellently. Although excellent progress was made with the single cage it is said that with two balanced cages such as used in the Rondout and Wallkill tunnels, better progress could have been made because of greater freedom in sending materials in and out of the tunnel. The need of quicker hoisting facilities was felt more keenly during concreting, when even two cages are hard pressed to lower concrete as fast as it can be placed in the forms. To increase the capacity of the West shaft for concrete, the single cage was equipped with a $1\frac{1}{2}$-yard hopper dumping from two sides into concrete tunnel cars upon reaching the bottom.

The tunnel was concreted through the West shaft, as the East shaft is much more complicated and lined throughout its depth.

"Holing" through of Hudson Tunnel. On Jan. 30, 1912, Mayor Gaynor in the presence of a distinguished assembly, including the Commissioners of the Board of Water Supply, and various City officials, fired the shot which broke down the rock wall separating the east and west tunnels, so that those present could walk through a hole in solid rock 1100 feet below the surface of the river. This was signalized by the Mayor as the culmination of the greatest feat in water supply construction since the dawn of history, far out-

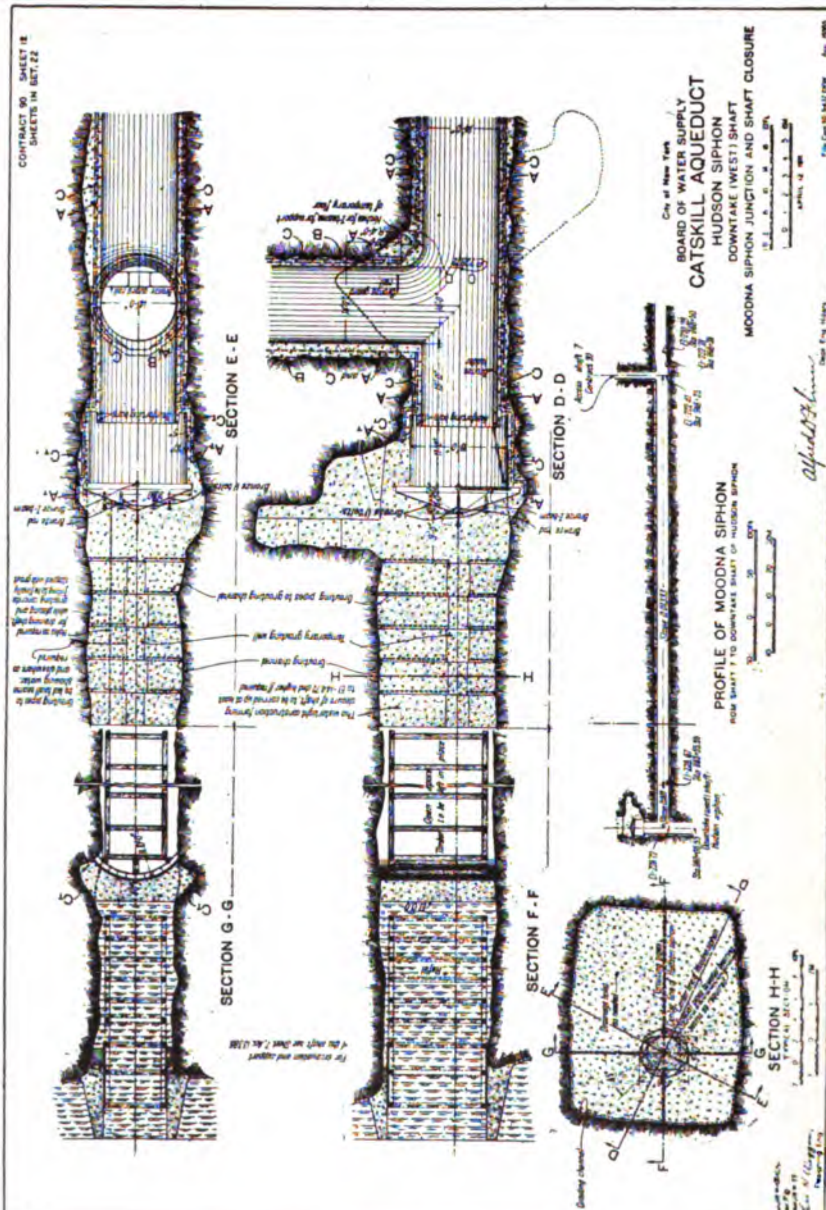


PLATE 142.—Junction of Moodna Siphon and West Shaft at Hudson River. Method of "plugging" shaft, etc.

ranking the Roman aqueducts in size and durability of construction. At that time nearly 80 per cent of the construction essential to the delivery of the Catskill water to Croton Lake was completed, and there remained no difficult portion of construction which was not far enough along to cause anxiety as to its completion.

The Hudson tunnel when holed through could be walked dry shod from shaft to shaft, large portions of the walls being bone dry, what little water there was appearing in few wet streaks. To give the pumps a little work, all the water in the shafts was allowed to flow to the bottom, where after the sumps were filled the electric pumps were run till they were emptied, this being done to keep the pumps in running order. They later were removed from the tunnel, so that the concreting could be proceeded with.

Concreting of Tunnel. A very convenient plant was installed at the top of the West shaft to supply concrete for the entire tunnel. Barges of sand and broken stone were unloaded at the dock by a derrick and grab bucket, which filled a small hopper feeding onto a belt which in turn discharged into a longitudinal belt over the sand and stone bins near the shaft. The belt over the bin was equipped with a tripper so that the bins could be kept uniformly filled. The concrete measuring and charging cars were filled from the bins and hauled by a small hoist up an incline to a large Smith mixer, which discharged a batch twice the usual size directly into a large twin-hopper car on the cage. This car at the bottom of the shaft automatically discharged into two cars, one each side of the shaft. The concrete cars were hauled by electric trolley dinkies to the forms, which were used in a manner very similar to that employed at the Wallkill and Rondout siphons. Although a 40-foot side wall and arch form was filled daily, it is reported that the single cage is a considerable handicap during concreting, as there was little time to take the hopper car off and use the cage for other purposes such as cleaning and mucking out tunnel, etc. A particularly rich mix, about 1–1½–3 (2 barrels cement per yard) was used for all the concrete in order to secure water-tightness. The lining averaged at least 17 inches effective thickness (see Plate 138).

Grouting of Tunnel. After grouting the ground-water head accumulated rapidly back of the lining, showing pressure, where grout pipes were kept open, up to 450 pounds per square inch. It is very remarkable how dry large areas of this concrete appears even with the enormous pressure back of it. Stretches show perfectly dry with not even moisture on the surface. At a few places, particularly near the wet seam near the East shaft, trouble was experienced in the grouting.

Most of the grouting was done under low pressure and ejected over the arch in the usual manner, using a Canniff grouting machine, air stirred, as described under Rondout and Wallkill siphon. The flowing pipes were wisely left open to the last to prevent the water from accumulating, under high head above the arch. To do the high-pressure grouting a very ingenious combination of air and water-pressure pump was devised. A Canniff machine was partly filled with grout which was placed under a pressure of about 350 pounds with a Westinghouse compressor connected as usual with the tank. Then a powerful Cameron pump with large air end and small water end was started and pumped water into the tank through another connection, reducing the volume of air above the grout so as to raise the pressure up to 600 pounds per square inch, if desired. The discharge valve of the tank was then opened and the pump kept going to maintain the pressure while the grout flowed slowly into the space back of the concrete lining. By this arrangement grouting under almost any pressure is feasible. Special heavy connections, of course, were used.

At a few points where large areas had been panned back of the lining and at joints in the concrete near water-bearing seams, the lining was slightly cracked by the enormous grouting pressures, but these cracks were repaired by cutting out patches of concrete so that new concrete could be keyed in. The grouting of the Hudson siphon due to the high pressures used was entirely unprecedented, but there is every reason to believe that it was successful.

Contract 80—Breakneck Shaft and Tunnels

Work and Prices. Contract 80, although only 2532 feet long, includes the construction of all types of tunnel and a shaft 589 feet deep, in addition to 710 feet of cut-and-cover. It connects the East shaft of the Hudson siphon with a stretch of cut-and-cover leading to the Bull Hill tunnel (Contract 22). This contract was awarded to the Dravo Contracting Company, June, 1910, for a total of $456,515, some of the unit prices being as follows:

Shaft excavation, cubic yard	$20.00
Excavation pressure tunnel, cubic yard	7.00
Excavation grade tunnel, cubic yard	6.00
Concrete shaft and tunnel, cubic yard	6.00
Forms for shaft, linear feet	5.00
Forms for pressure tunnel, linear feet	6.00

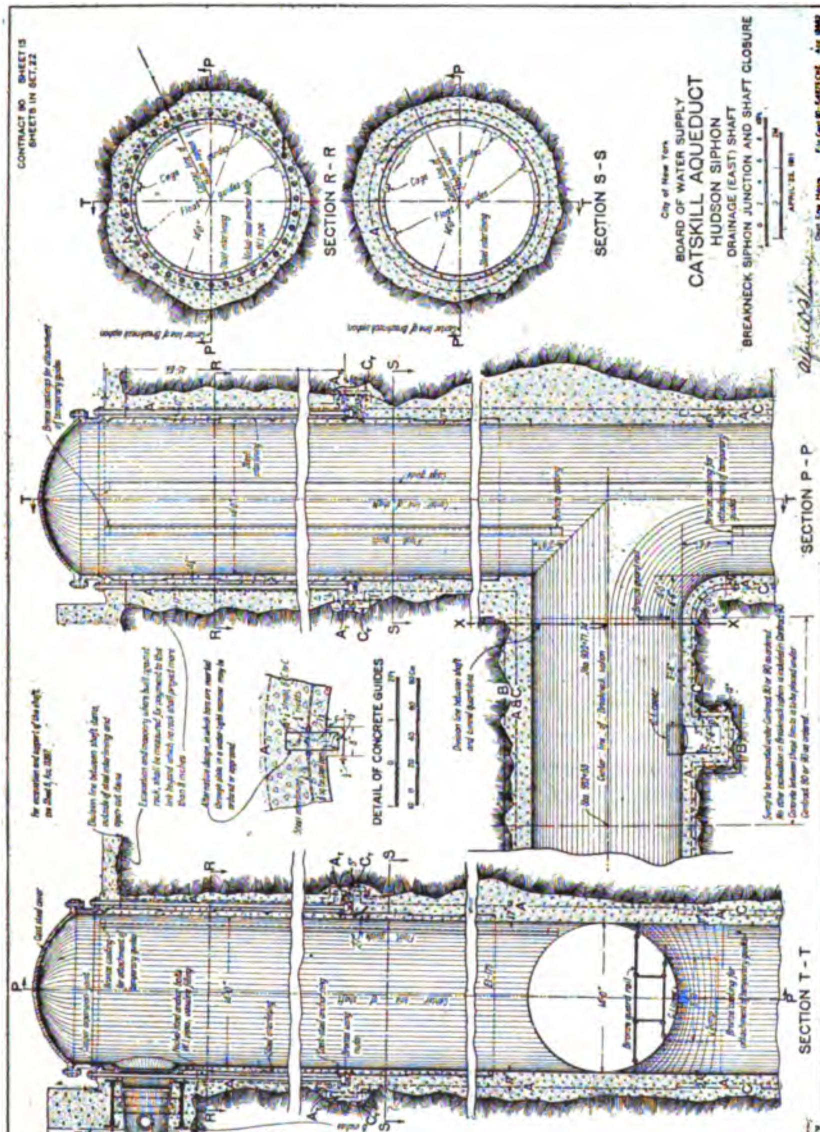


PLATE 143.—Contract 90. Junction of East Shaft at Hudson Breakneck Pressure Tunnel. Shows Shaft Cap for Closure, Concrete Guides, etc.

On the basis of contract quantities the linear feet cost of this work to the city is estimated as follows:

Cut-and-cover-aqueduct	$100
Grade tunnel	111
Pressure tunnel (including Breakneck Shaft)	358

The pressure tunnel starts at the East shaft at about elevation −195, and runs for 768 feet to the foot of Breakneck shaft (589 feet deep), at the top of which is the portal of the Breakneck grade tunnel penetrating the Breakneck Mountain for 1080 feet and terminating in a cut-and-cover aqueduct 710 feet long in Breakneck Valley.

Incline and Power Plant. To reach the hardly accessible Breakneck shaft and portal an inclined cable road was laid from the New York Central Railroad 1000 feet up the side of Breakneck Mountain with a rise of 400 feet to the shaft site. Cars were hauled up the incline by an air-operated Lambert hoist. The power plant for the entire contract was built adjoining the New York Central Railroad and consisted of four 100-H.P. Erie boilers furnishing steam for three compressors and one dynamo. The compressors had a combined capacity of 250 cubic feet air per minute and consisted of one Ingersoll-Rand 1350-foot compressor, one Sergeant 900-foot compressor, and one Rand 700-foot compressor. The dynamo supplied current to the the whole work. This power plant was transferred from west of the Hudson, where it had been used for sinking five of the Moodna shafts. A 6-inch air line conducted the air to near the base of Breakneck Mountain, where it branched into two 4-inch mains to the east portal and the uptake shaft.

Catskill Aqueduct Shafts Sunk by Dravo Company. The Dravo Company have sunk about 20 shafts and constructed many stretches of tunnel along the line of the aqueduct in addition to the work on Contract 80. This contract is remarkable for the methods employed and the wonderful record made in sinking the Breakneck shaft.

Record Shaft Sinking for the United States. The shaft was excavated and lined with concrete in stretches. In five months, from January to May, 1911, inclusive, 476 feet were excavated in granite, and 741 feet lined. Under Supt. Walter W. Steenburg the record shaft sinking for the country was done. Between March 8 and April 8, no work being done on four Sundays, 183 feet of shaft were excavated. A total depth of 588 feet was sunk in ninety-three working days, or 6⅓ feet per day. Total elapsed time was 118 days. The concrete lining, including 20 feet of bell-mouth and 541 feet of regular shaft lining, was placed in forty-six working days, in an elapsed time of fifty-three days.

The shaft was very accurately drilled, so that the excavation averaged about the C line. The organization of Mr. Steenburg also made the record at Shaft 1 of the Moodna tunnel.

Method of Excavating Breakneck Shaft. The shaft was excavated to an average diameter of 16½ feet by drilling two circles of holes, the inner or cut circle, 10 feet in diameter, contained ten 8-foot holes; the outer circle, 16 feet 6 inches in diameter, contained twenty 7-foot rim holes. All the holes were drilled in from 5 to 6½ hours with 3⅝ Ingersoll-Rand drills mounted on tripods. The cut holes were shot with the usual center or "buster" hole used to break up the muck to small size. After the cone blown out by the first round was sufficiently excavated the trimming holes were loaded and shot and all the muck removed in the third shift. The rock in this shaft was a medium hard gneissoid granite, uniform and dry. Conditions were favorable, as shown by the use of only two rows of holes, as against the three rows usually necessary. The record made at this shaft is in every way unique and deserving of all credit.

The Leyner Drill. Contract 80 was distinguished by the use made of the Leyner drill for tunnel driving. This drill was manufactured at Denver, Colorado, and has been used for many years in Western mines and in tunnels. It is now made by the Ingersoll-Rand Company, and called the Leyner-Ingersoll drill. Some of these tunnels, as that at Los Angeles and the Roosevelt Drainage tunnel, had been driven at record speed for the United States, and the Leyner drill, consequently, attracted a good deal of attention. Previous to the construction of the Catskill Aqueduct the drill had not been introduced into the East, but some of the contractors about to start long tunnels sent personal representatives to the West to examine the working of the Leyner drills and arranged with the manufacturers for a trial.

Leyner Drill at Rondout Tunnel. On the Rondout siphon the contractors found that but slow progress could be made with piston drills in Shawangunk grit, usually taking 12–16 hours to drill a heading, with a resulting large consumption of steel and high cost of resharpening bits, particularly the starters. As drilling in hard rock was claimed to be easily accomplished by the Leyner drill several of these machines were introduced and operated under the personal direction of a representative of the drill company.

The Leyner drill is essentially a hammer drill, and uses hollow steel through which a combined stream of air and water is blown to clear the bottom of the hole of chippings. For this purpose there is a double connection, one the usual air line and the other a small water line from a pressure tank or from a pipe with water under pressure. Drill holes as large as made by the usual piston drills are made by the Leyner drills.

The drills for the Rondout tunnel arriving before the grit headings were ready, were tried in a tunnel in Hudson River shale, and found to work very well, but were at a disadvantage in drilling down or vertical holes in the bench. On the other hand, they were particularly good for the so-called dry holes, or those pointing upward, as the Leyner drill readily clears itself in such a hole by the air and water. When first used in the grit tunnel, the drills were found to drill holes at a very much faster rate than the piston drills and were far more sanitary, inasmuch as they made no dust. The dust made by the piston drills in the dry holes while working in quartz rock is particularly dense and irritating to the workmen. After the drills were in operation a short time parts began to break, and as the Leyner Company did not furnish sufficient parts to keep them in repair they were replaced by Ingersoll-Rand piston drills.

Advantages and Disadvantages of Hammer Drills. Many advantages are claimed for hammer drills, the greatest being that they use less than one-half the power of piston drills; that they can be used by unskilled labor and do not require helpers, and that one skilled man can direct several machines. In practice, this is hard to attain. The hammer of the drill may weigh only a fraction of the combined weight of the piston and steel of the ordinary drill. This means, that to strike an equal blow the hammer has to travel many times as fast as the piston of the ordinary drill, thus causing crystallization in the hammer and steel, the hammer breaking itself, side rods, anvil blocks, etc., by its tremendous velocity and frequency of blows. In addition breaks occur at the cutting edges of the bits and in the welds. The water connections of the Leyner drill are also apt to cause trouble, particularly when the water used is not clean. The above disadvantages are cited not because they are insurmountable, but to illustrate the difficulties which have to be overcome before the hammer drill is perfected.

Leyner Drills at Wallkill Tunnel. The drill manufacturers were frank to acknowledge the defects of the drill as brought out by the

Rondout tests and claimed that in a newer model they were largely eliminated. Another and more complete test was arranged by the contractors of the Wallkill siphon. A shaft with its two tunnels was turned over to a representative of the drill manufacturers as superintendent; in this capacity he was given entire charge. An outfit of Leyner drills was employed in both tunnels. Unfortunately the work done at this shaft with these drills did not compare favorably in speed or cost with the work done at other shafts. This was due largely to the fact that the Leyner representative was not an experienced shaft superintendent, so that his organization with the Leyner drills could not overcome this disadvantage. This probably was not a good place for a drill test, as the rock was a very free-drilling shale, through which almost any drill could make sufficient progress. The problem here was not the drilling of the holes, but the removal of muck. With the percussion drills the tunnel heading was readily drilled and shot in less than eight hours, but unless the mucking arrangements were very good, the tunnel would be blocked.

Leyner Drill at Breakneck Tunnel. The third test of the Leyner drills at Breakneck was far more satisfactory than the other two. The rock drilled here was a gneissoid granite, locally known as the Storm King granite. It is a rather hard rock, but drills well, and is probably similar to the Western granite with which the Leyner drill had made its records. From experience on the Rondout and Wallkill siphons, it was known that it was difficult to break in the ordinary Eastern drill runner to use the Leyner drill. It is a comparatively delicate machine and cannot or ought not to be handled as roughly as the simple piston customarily is. In the Western mines and tunnels where the Leyner drills are used the pay of the drill runners is higher than in the East, and the men are said to be better mechanics and more capable of keeping the drill in running order.

An organization of Western drill runners was brought East and placed in charge of a tunnel on Contract 80. The drill worked well under their charge, but the method of placing holes in the tunnel was not to the liking of the superintendent. In driving Western drifts or drainage tunnels, it is customary to place the holes at a slight inclination to each other and to rely on powder heavily loaded in the numerous holes to pull the cut. This was considered wasteful and new men were obtained. The superintendent found that it was very hard to overcome the prejudice of the ordinary drill runner against the use of the Leyner drills, or, it might be better stated, to change the habits of the ordinary drill runner acquired in running piston drills. It was found that any intelligent man unaccustomed to drills could soon be broken in to run the Leyner drills and do very good work. While working, the footage was considerably higher than the piston drills, but they were still subject to breakdowns.

The Leyner drills made 5 feet per hour in granite, drilling a round in about ten hours. Later, in the arch they made 7 feet per hour, drilling the round in $5\frac{1}{2}$ hours. The bottom heading was drilled with eight $7\frac{1}{2}$-foot cut holes and seventeen $6\frac{1}{2}$-foot side holes. In the arch eight to sixteen 10-foot holes were used. Taking into account the time lost in repairs, their performance was about the same as the piston drills. It is said that the Leyner drill was considerably improved during this work, it being found that by the use of a heavier and better material in the cylinders and other parts of the drill much of the trouble could be eliminated.

Leyner Drill at Contract 30 (Hill View). The Dravo Company used the drill later on Contract 30, driving the pressure tunnel at Hill View Reservoir where they did excellent work, giving much less trouble than previously, due to improvements in workmanship and materials, and reducing time of drilling hard gneiss materially. The tunnels here, however, were rather short, and the test can hardly be said to be conclusive.

Merits of Leyner Drills. It would seem that the Leyner drill has many distinct merits, and that if its defects can be overcome its use in driving tunnel headings should increase, and should be encouraged for the reason that it eliminates the dust of drilling, the breathing of which undoubtedly shortens the lives of tunnel workmen. The Leyner drill is now manufactured in the East and has been placed on the market in an improved form—as the Leyner-Ingersoll drill.

Excavation of Breakneck Tunnel. Breakneck grade tunnel was excavated with a bottom heading, drilling being done by Leyner drills operated on a horizontal shaft bar. After a portion of the muck had been removed the horizontal bar was blocked across the heading and drilling progressed while mucking was going on. With vertical bars it is necessary to muck the face to the floor of the heading.

Crushing Plant. From the east heading the muck was run to a crusher plant, consisting of a No. 5 rotary Gates crusher and a No. 4 Champion jaw crusher. After being crushed the stone was elevated to a rotary screen and separated into dust and stone, the stone being piled by a conveyor belt around a wooden tunnel into which cars were run and filled by gravity. This was probably as economical as any crushing plant operated in connection with a tunnel.

Bottom Heading. The method of excavating a complete tunnel in connection with a bottom heading by shooting the arch or top half with horizontal holes down onto a portable timber platform was tried, but was soon abandoned as costly and slow. The supposed advantage of this method is that mucking can be readily done by loading cars below the platform through trap doors, without materially delaying the work in the bottom heading. Actually, the platforms were frequently broken by shots and were cumbersome to move and set up. Considerable muck also fell down on the lower track, requiring several men to keep it clear. The method is a crude adaptation of that used in Swiss tunnels. The resemblance is not very real, however, as in the Alps a small bottom drift is excavated and timbered with frequent upraisers to the tunnel roof, the material from the upper headings and enlargements being loaded through trap doors into cars on tracks below.

The method used in the bottom headings at Breakneck approximated closely that used in Western drainage tunnels, but as the tunnels were short no good comparisons can be made. It may be said that the rock was exceptionally good and sound, requiring no timbering. The tunnels were also dry, so that the placing of the horizontal bottom holes was not impeded by water.

Excavation above Bottom Headings. After the headings were driven through, the top half was taken down by drilling horizontal holes and shooting the material from the arch to the bottom of the tunnel, after which the drilling was resumed by setting columns on the muck pile. Very good progress was made in this work, about 170 feet being drilled and shot and 140 feet mucked per week. Methods similar to those described were used in the pressure tunnel.

Fuse-firing; Advantages and Disadvantages. The method of excavating the grade-tunnel bottom heading is here given in more detail. Two drilling shifts of four men and helpers were employed from 8 P.M. to 4 A.M., and 8 A.M. to 4 P.M., mucking being done by three mucking shifts of ten men each and one mule for pulling cars. All the heading holes were loaded at the same time and shot with time fuses of lengths such as to pull the cut holes first, then the side round and then the trimming holes. The men were able to return to the face in from fifteen to thirty minutes after touching off the fuses. By this method a round was generally pulled, but often some of the individual holes missed fire, resulting in a shorter advance and the finding of dynamite in the muck. Fuse-firing saves a good deal of time in shooting a heading over the usual method of shooting with electric detonators. The method of drilling and firing in Breakneck tunnel is common to the West, but very unusual in the East, where a strong prejudice exists against the use of fuses, it being thought that electric detonators are more reliable. Until recently firing with fuses was prohibited in New York City, but it is now allowed in the tunnels. Electric firing has one great advantage, as frequently the first shot fails to pull the cut, necessitating reloading. In such cases fuse-firing results in shorter advances and wasted drilling. Some experimenting has been done with "delayed action" electric fuses to enable a whole face to be shot in one circuit, in a manner similar to fuse-firing, thus saving the time consumed in loading three rounds separately. Apparently the "delayed action" fuses are not yet perfected.

Concreting. The concreting of the cut-and-cover, pressure and grade tunnels was done with Blaw forms, using the usual methods. The shaft was concreted with the aid of Dravo forms similar to but somewhat heavier than the Blaw forms.

Wire Cage Guides at Breakneck Shaft. Instead of the usual timber guides attached to the concrete lining of circular shafts for the operation of cages, cable guides were installed at Breakneck shaft. A single cage was installed and operated in wire guides attached to the head frame and to anchor bolts at the bottom of the shaft. The guides were of $1\frac{1}{4}$-inch galvanized wire rope passing over sheaves at the top of the head frame and attached to it by two steamboat ratchets used to take up slack. Only three days were required to brace the head frame and put in the cable guides. The cage was manufactured by the Connelsville Machine Company, and contained two long oak blocks at the side through holes in which the guide cables passed. Steel wedges were held by a spring clear of the guide cables when the hoist rope was taut. These wedges were thrown by the springs against the guide cables when the hoist rope was slack and served as a safety clutch, and apparently did this work well. Although the cage with cable guide proved very economical to install and worked satisfactorily for the single 800 feet of tunnel at the bottom of the 600-foot shaft, a single cage would not have been sufficient for a double tunnel, nor could two cages with cable guides operate safely in a shaft allowing small clearances between cages, as cable guides are flexible and would allow two cages to collide while passing. The action of safety clutches is not so certain on wire rope as on wooden guides, which, on the whole, are more satisfactory although considerably more costly in installation.

CONTRACT 22. BULL HILL TUNNEL.

Work and Prices. This contract was let March, 1909, to Patterson & Co., the lowest bidder, for a total of $824,942. Some of the items are as follows:

Open-cut excavation, cubic yard..............	$0.75 to 1.50
Refilling and embanking, cubic yard..........	0.50
Concrete masonry in open cut, cubic yard.....	5.50
Rock excavation in tunnel, cubic yard.........	6.00
Timbering in tunnel, M. feet B.M............	60.00 to 70.00
Concrete in tunnel, cubic yard	5.90
Forms for lining tunnel, linear feet............	2.00
Portland cement, barrel......................	1.70

The tunnel will cost the City about $110 per foot and the cut-and-cover about $101 per foot.

Progress and Methods in Bull Hill Tunnel. This contract consists mainly of the construction of Bull Hill tunnel, 5365 feet long. It penetrates the mountain, which is one of the most prominent features of the Highlands on the east bank of the Hudson a few miles above West Point. A compressor plant was installed at the river and equipped with three compressors, each of 1160 cubic feet capacity. The air was delivered to the north portal through an 8-inch main, and then through a 6-inch line over Bull Hill to the south portal. In the north portal heavy ground was encountered, necessitating the excavation of wall plate drifts and the use of permanent timbering for a distance of 200 feet. The south portal was excavated with derricks and the tunnel heading started. The rock in the tunnel proved to be a hard granite requiring no timbering. The excavation was made by the usual heading and bench method, using four drills for heading and two for bench. An average progress of 40 feet per week of complete tunnel was made.

On October 1, 1910, the work was taken over by friendly receivers, Barker & Shaw, and was conducted by them without much delay.

Concreting of Bull Hill Tunnel. An inclined railroad for hauling cement, sand and other material to the work was built, extending from the power plant at the river up Breakneck Valley to the aqueduct, and operated by a cable and hoist at the top of the incline. A crushing plant was installed at the north portal spoil bank to provide concrete aggregate. Blaw grade-tunnel forms of the usual construction were installed in the tunnel in three places, one 40 feet long and two 30 feet long. The concreting was carried continuously through three shifts, a new form being started as soon as it was ready. Concrete was hauled up inclines in the usual manner, but time was saved by depositing enough dry concrete on the platform to enable about one-half the key to be completed after the incline was removed.

Concreting Record for Grade Tunnels. It took a form gang about five to six hours to strike, move and set up a set of forms. From the south portal concrete plant, 2772 feet was concreted in ninety-six days, or 29 feet per day. From the north portal plant 2592 feet was concreted in fifty-nine days, or 44 feet per day. In one week, working seven days, 340 feet of arch was concreted, the best weekly progress so far made in grade tunnels, but later exceeded in the Garrison tunnel, where 593 feet was concreted in one week. The haul to the three sets of forms was 1500 feet, 2300 feet and 2900 feet. The shortest time for concreting a form was twelve hours; the longest, twenty hours; the average, fifteen hours. From 8 to 10 men and a foreman shoveled concrete, 4 to 6 mules and drivers hauled cars, 4 men and foreman were at the mixer, and a foreman and 8 men moved the forms, with 4 men to put on plates during concreting.

Comparison of Peak and Bull Hill Concreting. The average progress per working day was 35 feet in concreting this tunnel against 38 feet per working day in the Peak tunnel, Contract 11. As the work of the Peak tunnel was organized on the basis of two concreting and one moving shift against straight three-shift work for the Bull Hill tunnel, it is probable that the method of the Peak tunnel was more economical, as it had the advantage of the bulk of the work being done on the day shift.

Cut-and-Cover. The cut-and-cover was largely rock, earth-covered, which was excavated by drag scrapers and by traveling guy derricks lifting the skips, the material being run back to make refill. The concreting was done with Blaw forms. Bottom-dumping buckets were used, hauled by dinkies on flat cars and placed by the traveling derricks.

CHAPTER XII

PEEKSKILL DIVISION CUT-AND-COVER AND GRADE TUNNELS

CONTRACT 2

Location and Work of Contract 2. The first main contract was awarded April, 1907, to the Thomas McNally Company of Pittsburgh, Pa. Work on the location and preparation of the property maps and contract was rushed, as it was deemed important to have this work finished ahead of any other portion, as it made possible the delivery of additional water to the Croton watershed by diverting the Peekskill or other streams of the Highlands which this work crossed. This contract embraces all the work of the Peekskill Division with the exception of three pipe siphons at Indian and Sprout brooks and Peekskill creek. It traverses the Highlands between Cold Spring and Peekskill, the roughest and most difficult country between the Catskills and New York, and includes about 8 miles of cut-and-cover and 2.8 miles of grade tunnel, known as Cat Hill, Garrison and Mekeel tunnels. The Garrison tunnel is the longest grade tunnel in the Aqueduct, having a length of 11,430 feet. It was to be constructed from a shaft and two portals, but due to difficulty at the north portal other shafts were sunk.

Contract Prices. The total contract price was $4,126,423. Some of unit prices are as follows:

Excavation in open cut per cubic yard........	$0.94 to 1.33
Refilling..................................	0.26
Concrete masonry in open-cut aqueduct, cu.yd.	4.29
Rock excavation in tunnel, cu.yd.............	3.27
Concrete masonry in tunnel, cu.yd............	5.61
Forms for masonry lining, linear foot.........	4.12
Portland cement per barrel..................	1.85

Estimated cost of cut-and-cover aqueduct based on contract quantities is $71.63 per foot; of grade tunnel, $76.30 per foot.

Work of the First Year, 1907. The prices for cut-and-cover are considered fair when judged by other contracts, but the tunnel excavation figure is very low, and accounts largely for the subsequent history of this contract. As this contract started much in advance of any other, methods for doing this type of work had to be developed. Mr. McNally previously had large experience with the steam shovel for railroad work, and several of these were obtained and put to work excavating the trench for the aqueduct. A considerable amount of excavation was acccomplished during the first year, but the material was disposed of in a rather haphazard way, being cast to one side of the trench or disposed of in embankments adjacent to the aqueduct. Short stretches of track were laid alongside of the trench but were not connected by any particular plan for any considerable distance. A few culverts were built and a few roads relocated during the same year.

Garrison Tunnel, 1907. The main shaft of the Garrison tunnel was sunk to grade during 1907. It was found that at the north portal the rock was about at the level of the tunnel roof, the material above being wet glacial drift. This necessitated very heavy timbering, and such slow progress was made that it was decided to sink a pump shaft 380 feet south of the portal, its depth being only 61 feet. The contractor seemed to have been bothered by insufficient working capital, and particularly so as 1907 was a year of financial panic.

Plant on Hand, 1908. When work started in 1908 the contractor had on hand the following plant: Two 38-ton Marion steam shovels; four 70-ton Bucyrus steam shovels, locomotives, cars, track, etc.; also compressor plants at Garrison and Cat Hill tunnels. During this year the first concreting of aqueduct was accomplished. For this purpose, three distinct plants were used, but these were radically changed from time to time. All the plants were served by locomotives and trains on 3-foot gauge tracks, running to cement sheds, sand pit and both crusher plants. There was considerable interference of trains due to incomplete and faulty arrangements of tracks.

Concreting Plant, 1908. One of the first plants used on Section 2 consisted of a Foote continuous mixer mounted on a traveler running on rails laid on the concrete invert just outside the interior of the aqueduct. The various hoppers for the mixers were filled by a Browning locomotive crane similarly mounted on a traveler. The concrete was delivered by the mixer to end-dumping cars running on parallel tracks above the top of arch. Various minor modifications of this plant were tried, but the best results were obtained by the above arrangement. The locomotive crane was wrecked before the end of the season, and for it was substituted a derrick, installed at the side of the trench. This plant was handicapped by the fact that materials could be supplied to it only with difficulty on account of the poor track arrangement, also by the necessity of building tracks on top of the forms and the instability of the crane mounted high in the air on a traveler. It contained, however, all the elements of the plants later successfully used. The locomotive crane should have been placed on tracks alongside of the cut and the mixer in some location convenient to the materials, so that the concrete could be run directly to the crane over suitable tracks and directly placed between the forms. The concrete for key blocks and invert for about 1000 feet of invert was mixed in a stationary Hains mixer and conveyed in bottom-dumping buckets which were placed by locomotive cranes. The best success was obtained with this plant, and a great deal of invert concreted by substantially the same method as was used in subsequent contracts, except that on Contract 2, during this year, the track arrangements were always inadequate.

Casting of First Arch, July 13, 1908. The first section of arch of the entire aqueduct was concreted on July 13, 1908. The plant here used consisted of 1-yard Smith mixer fed with sand and stone from hoppers mounted on a car running on a standard-gauge track alongside of the aqueduct trench. These hoppers were filled by an A-frame derrick mounted on the same track. The concrete was placed in the forms by aid of another A-frame derrick. It is interesting to note that this 30-foot section of arch took about twelve hours to be concreted. With later plants on other contracts this could easily have been done in two or three hours. The mixer was subsequently mounted on a traveler running on the finished invert. On the same traveler were mounted a boiler and hoist which raised from the tracks skips of proportioned concrete material. These skips were run inboard on a trolley running on a cantilever arm at right angles to the track, and discharged directly into the mixer which in turn discharged into the side-dumping cars running on a track above the form. This plant was slow and awkward in operation.

Hains Mixer Plant. The best progress in concreting was made with the stationary Hains mixing plant, which discharged into $1\frac{1}{2}$-yard bottom-dumping buckets carried on platform cars hauled to the side of the work by dinkies, where they were dumped into the forms by locomotive cranes. This plant was similar to that subsequently used on Contract 11, where the maximum progress in concreting cut-and-cover aqueduct was made. The McNally plant, however, was not provided with proper trackage, so that materials could not be rapidly hauled to and from it.

First Steel Forms Used. The first steel forms in use on the aqueduct were designed and built for this contract. They were collapsible in 5 foot-sections. The inside forms were mounted on a carriage equipped with jacks. As the proper carriage and method of collapsing steel forms were not yet worked out they gave considerable trouble and were moved with great difficulty. The outside forms were constructed of steel ribs connected with the inside forms by rods or wires. Between the I-beam ribs tongue-and-groove lagging in 5-foot lengths was inserted as the concrete rose. Wooden transverse bulkheads were used in which were inserted the steel plates used to prevent leakage from expansion joints. During the season of 1908, 4385 feet of invert were laid and 1485 feet of arch. At the Garrison tunnel about 1150 feet of tunnel was excavated from the main shaft, and a short stretch of timbered top heading was driven from the auxiliary shaft near the north portal. Some progress was made in the north portal heading, and about 500 feet of the Cat Hill tunnel was also excavated.

McNally Receivership, 1909. During the latter part of 1908 the contractor operated with considerable difficulty, and early in 1909 receivers were appointed to carry on the work. The work was subdivided into four parts by the receivers, and they were let to the following superintendents: John J. Hart, work south of Peekskill Creek; Cleveland Tunnel Construction Company, Cat Hill tunnel, and adjoining section of cut-and-cover of the south, comprising work between Peekskill and Sprout Brook siphons; Gore-Meenan Company, Garrison tunnel and adjoining cut-and-cover, comprising the stretch between Sprout Brook and Indian Brook. This last company operated until March, 1910, when it in turn failed and the work was then taken over by the Hicks, Johnson Company, Inc. The north end, comprising the cut-and-cover work north of Indian Brook, and Mekeel tunnel, was under R. K. Everett & Co., known subsequently to September, 1911, as the Spring Hill Construction Co.

R. K. Everett Work. The work of this company comprised the Nelsonville cut-and-cover, 3574 feet; the Mekeel tunnel, 900 feet; and the north end of Garrison cut-and-cover, 3900 feet. No work had been done on this section by the McNally Company, the original contractor, so that the new company had opportunity to work with a plant and plan of their own. The excavation in earth was made with a 70-ton Bucyrus steam shovel. In rock cuts stationary derricks were installed on the downhill side and used for hoisting rock from the trench and building

PLATE 144.—Contract 2. Cut-and-cover Aqueduct. First steel forms—McNally—used on Catskill Aqueduct. Outside forms are of steel ribs and wooden lagging. Wooden bulkhead contains steel plate to act as water stop at expansion joint.

a heavy dry rubble retaining wall on the lower side. Throughout a great portion of this section the aqueduct is located on a steep sidehill, and is to a large extent inaccessible. The northerly 1300 feet was an easy country and operations were begun here, the contractor planning to have the trench ready for concrete as the construction proceeded southward; also to install a crusher plant where rock was available from the cuts and to build a track for conveying material along the line of the work.

Mekeel Tunnel. The Mekeel tunnel was excavated by ordinary heading and bench method from one end, but despite its shortness was the scene of one of the worst tunnel accidents, several men being killed in the heading by a premature explosion.

Concreting of Mekeel Tunnel. The Mekeel tunnel was concreted with the aid of Blaw tunnel forms. The concrete from a mixer at a portal was discharged through a chute directly into concrete cars. These cars were carried on an elevated platform, two or three at a time; the platform ran on rails and at the same elevation as the form platform, so that the cars could be run on the forms and dumped into place. This saved the work of constructing an incline and operating a hoist as usually used. It was well adapted for a tunnel only 900 feet long, but could not well be used in a longer tunnel where it is necessary to pull the cars through the form. The platform was hauled to and fro by mules.

Cut-and-Cover Construction Plant. During 1909 considerable aqueduct trench was excavated, but due to the delay in the installation of the crusher plant, it was necessary to leave an earth trench with steep slope standing over winter. A large amount of caving resulted and the bottom of the trench had to be re-excavated the following year. The following concrete plant was used in the construction of the aqueduct: No. 4 Ransome mixer located in the trench was served by a stationary derrick, the materials being brought in trains on the construction track. Concrete was deposited in the forms by a traveling derrick. Ordinary steel forms of the Blaw type were used and handled in the same way as previously described under other contracts.

Special Foundation Work. In order to secure the aqueduct, which was here built along the steep slopes of the Highlands, special precautions were taken to obtain suitable foundations. Where the bottom was entirely in rock the invert subgrade was generally cleared of all débris and the concrete carried down to firm rock. Where the rock fell considerably below subgrade on the downhill side the foundation walls, about 5 feet wide, extending parallel to the center line, were carried down to rock or other solid material. In some places transverse steel rods were used in the invert for reinforcement.

Cat Hill Tunnel. Cleveland Tunnel Construction Company. The work of this company included the Cat Hill tunnel and adjacent sections of cut-and-cover. The tunnel had been partly excavated by the McNally Company, and was completed by the Cleveland Tunnel Company, by the ordinary top heading and bench method, although considerable heading was driven before the bench was started. This tunnel illustrates the costliness of not driving to required section or line. Due to inadequate plant and frequent changes of force, the tunnel was so driven by the McNally Company that much costly trimming was necessary to make room for the tunnel lining, and, in addition, a large amount of dry packing and excess concrete were necessary outside the required thickness of concrete lining. This dry packing occupied spaces where the tunnel was driven wide or out of line.

Concreting of Cat Hill Tunnel. A common crushing and mixing plant supplied concrete to both the tunnel and cut-and-cover, and consisted of a Gates crusher, bins and two ½-yard Smith mixers. The method of concreting was similar to that used in the Bonticou and other tunnels, except that 20-foot stretches of Blaw forms were concreted at a time, the cars being raised from the bottom tracks by an electric driven elevator to the level of the shoveling platform. This elevator was constructed to avoid the use of incline and hoist such as is commonly used, but it is doubtful whether it is an improvement, as the incline has a large capacity, being able to raise two or more cars in trains, whereas the elevator was good for only one car at a time.

Cut-and-Cover Work. The upper lift of the cut-and-cover excavation (mostly rock) was removed by steam shovel in 1908. A cableway of 250-foot span was erected for finishing the work of excavating. The excavated material was hauled in cars by mules or small locomotive. The cableway was moved from place to place along the center line. This is one of only a few instances on this work known to the writer where a cableway was used for excavation of cut-and-cover aqueduct trench. It was given serious consideration by other contractors, but they came to the conclusion that it was not adapted to this kind of work. Blaw steel forms were used and concrete deposited in them by means of traveling crane running on the invert. Side-dump cars or buckets were hauled, from the central plant.

John J. Hart Work. The work comprised 3.9 miles of cut-and-cover between Peekskill Creek and Hunter's Brook siphons. At the time work was suspended by the first contractor, it was about 22 per cent completed, though it was the section upon which most of the work had been concentrated. The plant left on this work was taken over and after additions and various improvements had been made, worked to very good advantage.

Cut-and-cover Plant. An excellent plant was remodeled adjacent to the Coleman, Breucheud & Coleman quarry from which a large proportion of the stone used on the new Croton dam was taken. Waste and quarried rock after being run through a crusher were conveyed directly to bins over a No. 4 Ransome mixer. Concrete was transported in 1½-yard bottom-dump buckets in flat cars and deposited over forms by locomotive crane. The original set of McNally steel forms, which were in poor shape, were discarded, but the second set was partly rebuilt and mounted on a traveler with jacks. The outside forms consisted of steel frames with wooden lagging in 16-foot lengths. The interior forms were not run telescoping, as previously attempted, but were operated by the spacing-out method previously described under Contracts 11 and 16, but first here used on any notable scale by Mr. Hart. The plant described above was the first complete aqueduct building plant in operation and with it excellent work was done; for a considerable period, about 45 feet of arch was concreted per day. For other portions of the work new Ransome telescopic forms were used. These forms were mounted on a hand-operated carriage. They were operated around curves by means of overlapping plates, which, however, did not give smooth joints. The McNally forms were made to conform to the curves by bolting wedge-shaped fillers between adjacent sections.

Traveling Concrete Plants. Use was also made of two remodeled traveling plants left by previous contractors. These travelers were of timber construction with two decks, the whole running on rails laid near outer edges of invert. On the top deck was a large mixer, two boilers with hoist and a stiff-legged derrick for hoisting the dry batches from the cars, running alongside of the trench, to the mixer. For casting arch the traveler was run against the end of the steel form, and the material from the mixer was dumped into a car on rails laid over channels forming the top of the steel frames for outside forms. The car was dumped at the desired place directly into the forms. The car was W-shaped, so that half of each batch would fall each side of the arch. Concrete for invert was mixed by a small

PLATE 145.—Contract 2. Cut-and-cover Aqueduct Building Plant. Stone crushed and concrete mixed at plant in distance. Concrete hauled in buckets to forms and placed by locomotive crane. Steel inside forms, outside forms of steel ribs and wooden lagging. First complete plant of this type.

mixer on the lower deck which discharged into the side-dump cars operated on a track laid on a wooden trestle in the center of the trench. These travelers worked fairly well, but apparently are not as economical or as flexible as the ordinary method of depositing concrete directly from the locomotive crane. The main advantage of the traveler appears to be that use is made of the space over the invert and it can be served by a single track. Another advantage is that the concrete is deposited in place soon after being mixed. However, it has been found on other contracts that concrete can be successfully hauled over a mile and deposited.

Excavation and Refill. Considerable of the excavation of this section was done by the McNally Company (except about 3000 feet at the south end and some intermediate stretches), the chief of which were the heavy rock cut at the north end, the Todd cut for a maximum depth to subgrade of nearly 55 feet at Crompond Road crossing and quite an extensive rock cut south of the Coleman, Breucheud & Coleman quarry. The rock cuts were excavated with stationary derricks and the spoil hauled away in trains, all suitable rock being used at the crusher plant. At the heavy Todd cut a 70-ton Buycrus steam shovel, a locomotive crane and an orange-peel bucket were used. At the south end of the cut a Lidgerwood cableway with 55-foot towers and 840-foot span was used to convey the spoil, the skips being loaded partly by hand and partly by steam shovel. The excavated material was deposited at the side of the trench, or part used for refill over the aqueduct. Part of the excavation and refilling was done at night. Considerable refill was also placed by a locomotive crane and clam-shell or orange-peel bucket, handling the material originally excavated and placed at side of trenches. This crane had to be assisted by men with pick and shovel, as the material had consolidated through standing several years.

Gore-Meenan and Hicks-Johnson Work. After the McNally Company went into the receiver's hands, the Garrison tunnel and 7670 feet of cut-and-cover north of the tunnel and 3350 feet of aqueduct south of the tunnel were given to the Gore-Meenan Co. This company, handicapped by lack of capital, was forced to give up the work, which was continued later by the Hicks-Johnson Company, Inc. This company considerably reinforced the plant of the main shaft by adding a 500-H.P. Sterling boiler and an Ingersoll-Rand compressor of 2400 cubic feet capacity. Electric locomotives were also installed to haul muck in the tunnel.

Garrison Tunnel Excavation. This company prosecuted the work with vigor and on October 4, 1911, the headings between the main and north shafts met. The south heading from the main shaft continued in hard, compact granitic gneiss until September, 1911, when a variable flow of water, amounting to about 100 gallons per minute, was struck in a seam between hard and soft rock. Work was suspended for a while, but the bad ground was passed by careful timbering. At the end of 1911 there remained 1175 feet between the two headings, and the headings met in May, 1912. This makes elapsed time five years of work on the excavation of the Garrison tunnel alone, a much longer time than has been taken on any other tunnel, much longer even than on the Hudson siphon with its 1100-foot shafts, and a year longer than the Rondout siphon, although the Garrison tunnel is only 2.1 miles long. The delay in excavating this tunnel was caused mainly by the low unit price bid for excavation of tunnels, thus well illustrating the fact that physical obstacles are more readily overcome than financial.

Soft Ground at North Portal. The Garrison tunnel, nevertheless, was by no means an easy one. The rock as a rule was very hard and the numerous streams of water met in the headings were very troublesome. There were several difficult points to be passed, the most difficult being that at the north portal.

The stretch of 700 feet of tunnel at the north portal has a very interesting history, extending over a period of five years. In 1907, in order to save delay in starting the excavation of the tunnel, a shaft was sunk at the contract portal, Station 604+80, to tunnel grade previous to excavating the deep portal cut. This heading was in rock and in earth, a wet glacial drift which brought great pressure upon the timbers. 380 feet from the portal shaft, at Station 601, a small pump shaft was sunk in September, 1908, 61 feet to tunnel grade, its purpose being to drain the earth and make tunneling easier. This shaft did not intercept much water, and it was pumped from only for a short period. At the same time a construction shaft 105 feet deep was sunk to tunnel grade at Station 598, 680 feet from the portal. A timbered heading 22 feet long was driven northward from this toward the difficult ground, when work was stopped and not resumed again till April, 1911, two and one-half years later. In 1911, 338 feet additional was excavated in the north heading. The face of the portal heading at this time was partly in quicksand, and it was thought advisable to sink a new shaft at Station 602+74, at the end of the portal heading, from which a new type of timbering could be advanced southward. This new shaft was sunk 34 feet in December, 1911, when about 100 feet of soft ground tunnel remained to be driven. This was holed through in February, 1912, completing the difficult stretch at the north portal.

Timbering Bad Ground, North Portal Garrison Tunnel. The material in the heading north of Station 598+00 consisted of a very soft, decomposed rock extending to within a few feet of the roof of the tunnel, overlaid by glacial drift—a blue hardpan with large boulders. The decomposed rock when first exposed was fairly firm and snow white, but the action of air and water caused it to soften and turn brown, so that very heavy timbering was required, and slow progress was made on account of the care necessary to prevent runs of earth and water. The first step was to drive a top center drift, about 20 feet long. In this drift the regular cap and leg bents of 8-inch timbers were placed, 4 feet center to center. Over these poling boards 2″×8″×5′ long were driven, two and even three thicknesses being required in some places. The next step was to post two crown bars 18″ to 24″ in diameter and 18 feet long, under the cross-caps. The step following was to take the legs one at a time from the bents in the drift and drive side poling boards over the crown bars at right angles to the center line. New bars were set to support the outer ends, just enough excavation being made to give room for the bar, after which additional crown bars were set and poling boards driven in the same manner until the full width of the roof was covered. After this the wall plates were set, supporting segmental timbers and lagging. The space above the segmental timbers was packed with stone as the work advanced. The last operation was to take out the bench (about 12 feet high) and post up the wall plates. The pressure on the timbers was so great that it was necessary to set the segmental timbers bent against bent and to use extra interior bracing. To secure the timbering it became necessary to begin concreting earlier than was anticipated, and the floor of the tunnel was concreted, beginning in December, 1911. Since April, 1911, 330 feet of heading and 342 feet of bench was excavated by the above method, about 10 feet a week, working three shifts in twenty-four hours. This progress is about the same as that made under conditions somewhat similar to those described under Eastview tunnel, Contract 52, in which tunnel compressed air was resorted to and the progress much increased. The question naturally arises whether a great deal of time might not have been saved at the north portal of the Garrison tunnel by the use of compressed air. Contract 2, however, unlike that of 52, contained no provision by which compressed-air work could be ordered by the engineers. It

PLATE 146.—Contract 2. Garrison Tunnel. Timbering in heavy ground. Roof timbers "block to block" on account of heavy pressures.

is stated, however, that experts employed by the contractors reported against the use of compressed air at this point.

Lining Garrison Tunnel. At this writing (February, 1913), the lining of Garrison tunnel is in progress. Six sets of Blaw forms, each 50 feet long, are distributed through the tunnel and served by mixer at bottom of main shaft. Side-dump cars, electric locomotives and inclines are used. The best week's progress so far (January, 1913), is 593 feet of completed arch.

Cut-and-Cover at Garrison Tunnel. The cut-and-cover work adjacent to the Garrison tunnel was excavated with steam shovel, locomotive cranes equipped with orange-peel buckets and very little by pick-and-shovel gangs loading skips. The crushing and concreting plant located near the north portal used stone direct from the tunnel, a stiff-legged derrick elevating sand obtained from the aqueduct right of way about 1500 feet distant. Concreting was done in the usual manner by bottom-dump buckets and locomotive cranes. Two hundred and eighty feet of the first McNally forms were used after extensive repairs. To move the interior forms a car was equipped with jacks to gradually strip the forms, pulling in at the bottom edge. A great deal of trouble was experienced here on account of the peeling of the concrete while removing forms. This was shown to be largely due to the use of a slow-setting cement which did not obtain sufficient set in some two to four days to overcome the adhesion of the concrete to the steel. After a quicker-setting cement was substituted this trouble largely disappeared.

Outside Forms. The outside forms, made of steel ribs and wooden lagging, were moved in an original manner. After being jacked up a few inches, they were pulled ahead on rollers resting on longitudinal rails, supported on the arch concrete at the back and on trestles on the inside forms in front. This had the advantage of requiring no locomotive crane or derrick, as the forms were moved forward in a full 30-foot section, and also did away with the necessity of taking the ribs apart and removing and setting up the wooden lagging.

CHAPTER XIII

STEEL PIPE LINES

CONTRACT 62

Contract 62—Prices. This contract was let in December, 1909, to the Snare & Trieste Co., for a total of $1,643,000. Some of the unit prices are as follows:

Earth excavation	$ .50 per cu.yd.
Rock excavation	2.50 per cu.yd.
Refill and embankment	.40 and .35 per cu.yd.
Control of streams	$2500
9 ft. 6 ins. steel pipe, $\frac{7}{16}$-in. steel plate, $\frac{3}{4}$-in. steel plate	$31 to 50 per linear foot
Mortar lining for steel pipe	2.50 per linear foot
Concrete masonry around steel pipe	6.00 per cu.yd.

Estimated cost of siphon chambers is $13,200 per chamber, of steel pipe complete $65.17 per foot, of cut-and-cover, $70.76 per foot.

Location. This contract embraces all the steel pipe lines to be laid in the Northern Aqueduct Department from Ashokan Reservoir to Peekskill, and consequently the work is spread out over a great stretch of country (about 60 miles). The siphons are isolated and each one was handled practically as a separate job. The advantage of combining the seven pipes was that a single contractor could secure better prices on a combined order for all the pipes; and also to a certain extent make the repeated use of forms and other plant possible. The seven siphons are as follows:

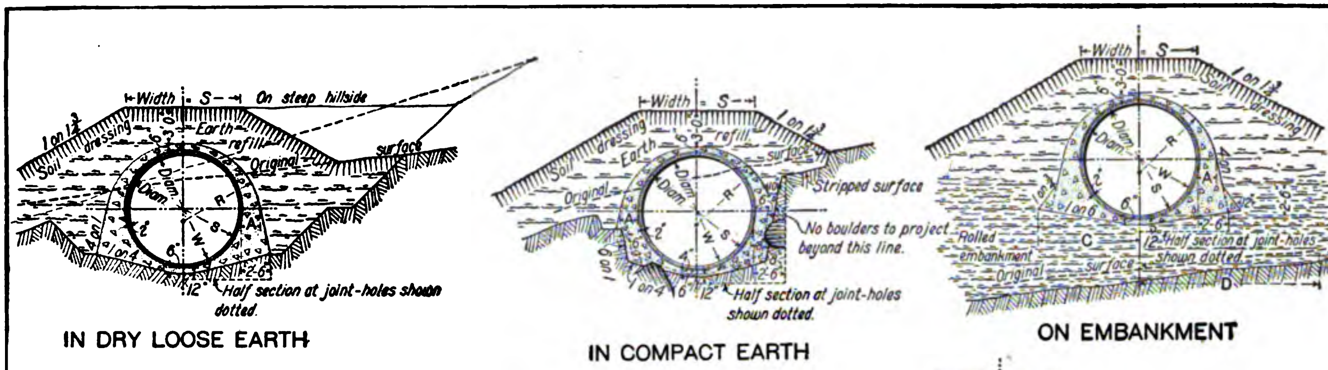
	Length of Pipe, Feet.	Max. Head on Pipe, Feet.
Esopus (near Brown Station)	2100	120
Tongore. " " "	700	80
Washington Sq. (near Newburgh)	3300	110
Foundry Brook (near Cold Spring)	3800	210
Indian Brook (near Cold Spring)	600	90
Sprout Brook (near Peekskill)	2200	260
Peekskill Creek (near Peekskill)	6700	360

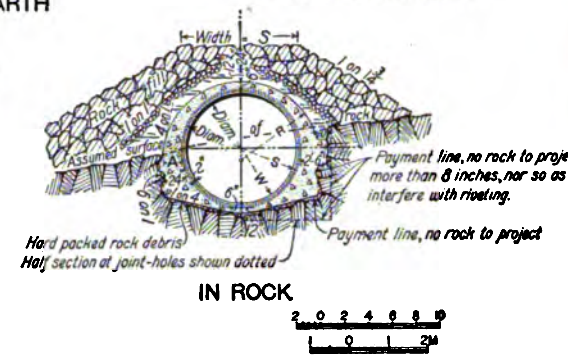
First Pipe Laid. Each one of these siphons consists of a single line of 9 foot 6-inch pipe with gate chambers at each end and adjacent portions of standard cut-and-cover aqueduct. The gate chambers are rather complicated structures equipped with sluice gates with $5' \times 13'$ opening and arranged for stop planks. They are built so as to allow the future installation of two additional lines of pipe, the single line contracted for being the central one. The single pipe line can easily carry 250 million gallons per day, the yield of the Esopus watershed. As it will probably be many years before other watersheds are made use of, the city will save the interest on the deferred pipes and also be the gainer in case there be any depreciation of such lines. To secure as permanent a construction as possible the pipes are surrounded by a heavy envelope of concrete 6 to 18 inches in thickness and lined with mortar 2 inches in thickness, the whole being covered with embankment in a manner similar to cut-and-cover aqueduct, which it is hoped the pipe will approach in permanency. Cross-sections of this construction are shown on Plate 147, and of siphon chambers on Plate 148.

Esopus Siphon. This siphon connects Contracts 10 and 11, crossing Esopus Creek about one-half mile below Olive Bridge Dam. A diamond-drill boring showed that below the north bank a preglacial gorge of the Esopus existed, so that shafts for a pressure tunnel would have to be disproportionately deep. The contract is drawn so as to allow this siphon to be delayed until after the closing of the dam, so that the pipe could be laid in the dry bed of the stream, a small culvert being used to carry the drainage below the dam. The contractor chose, in order to complete the contract, to lay the pipe previous to the completion of the dam. During the season of 1911 a temporary dam was built to permit of the excavation in the bed of the stream, but this dam was washed away by a flood and the work was resumed in 1912.

Tongore Siphon. About $\frac{3}{4}$ of a mile below the Esopus siphon is Tongore Creek, which has eroded a gorge 90 feet deep and 900 feet wide. The borings show the stream to have a much deeper preglacial gorge close to its present location, so it was decided to cross the present gorge by a steel pipe similar to that to be described under Indian Brook.

Washington Square Siphon. This is located in the Newburgh Division near a place of the same name. It crosses a depression 3300 feet long and 110 feet deep. Work was started in 1910. The steel pipe was hauled in wagons from the Ontario & Western





NAME OF SIPHON	NORTHERN AQUEDUCT DEPT.	SOUTHERN AQUEDUCT DEPT.	
	Esopus Tongore Washington Squa Foundry Brook Indian Brook Sprout Brook Peekskill	Hunters Brook Turkey Mountain Harlem Railroad Kensico	Elmsford Fort Hill Bryn Mawr
W = diameter of waterway	9 ft. - 2 in.	9 ft. - 5 in.	10 ft. - 11 in.
S = inside diameter of inside course of steel pipe = W+4 in. = top width of embankment)	9 ft. - 6 in.	9 ft. - 9 in.	11 ft. - 3 in.
R	6 ft. - 5 in.	6 ft. - 6¼ in.	7 ft. - 6¾ in.
A	18 in.	18 in.	21 in.
B	2 ft. - 6 in.	2 ft. - 6 in.	2 ft. - 10 in.
C	8 ft. - 6 in.	8 ft. - 8 in.	10 ft. - 0 in.
D	15 ft. - 0 in.	15 ft. - 0 in.	16 ft. - 6 in.

Outside diameter of steel pipe, from which thicknesses of concrete jacket are measured, = S+4t, t being thickness of steel plate which varies in the deeper siphons according to the pressure.

PLATE 147.—Steel Pipe Siphon. Cross-sections of construction in cut and in embankment. Table of dimensions of the various pipe siphons on Catskill Aqueduct.

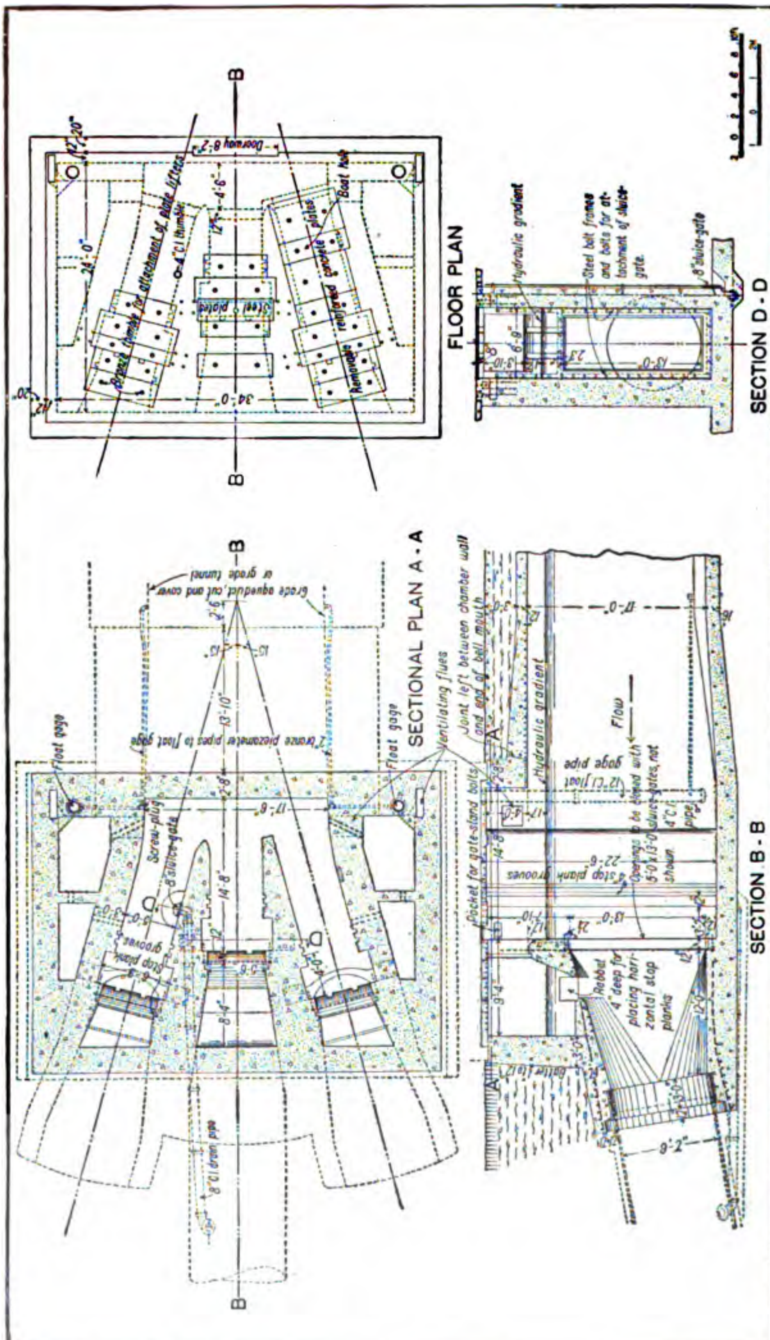


Plate 148.—Steel Pipe Siphon Chamber. Details of construction.

Railroad, 2½ miles distant, riveting and pipe laying here being done in the usual manner.

Foundry Brook Siphon. Next to the Peekskill siphon this is the longest on the contract. It crosses Foundry Brook about 1½ miles from its outlet at Cold Spring. Considerable boring work was done in this vicinity for a proposed pressure tunnel, but as some zones of decayed rock were found which apparently extended to considerable depth, the tunnel was given up in favor of the pipe siphon. Work on this siphon was started early in 1910, and vigorously pushed, so that by the end of the year the pipe had been entirely laid, riveted, tested, and partially concreted in. The gate chambers and several minor structures were practically completed.

To aid in the construction of this siphon a 650-foot cableway was used to span the stretch in the bottom of the valley, including the Brook crossing. Later this cableway was moved to concrete the northern portion. A railroad was built parallel to the pipe, over which cars were operated by cables and over the adjacent portion of the cut-and-cover by a dinky engine. The first work done was to build the retaining walls for a 30-foot culvert carrying Foundry Brook, which is spanned by the pipe siphon built as a tubular bridge with extra heavy sections. The contract included at the south end about 1700 feet of cut-and-cover, which was built in the usual manner.

Indian Brook Siphon. This siphon was one of the earliest started, and the methods of construction followed are typical for Contract 62. Indian Brook Crossing is about 3 miles by road from Cold Spring-on-the-Hudson. The stream flows through a narrow and very picturesque valley surrounded by large estates. At the point where the aqueduct crosses, it is well wooded and near a main highway.

Proposed Masonry Bridge. It was originally planned to construct a monumental arched bridge here, but this was abandoned, because previous experience has shown that it is difficult to maintain a large aqueduct crossing a bridge without great danger from leakage. In addition, a bridge is much more expensive. It was near this crossing that ground was broken on June 20, 1907, to mark the beginning of the construction of the Catskill water system.

Transportation. To secure the advantages of water transportation a dock was leased at Cold Spring, upon which was erected a stiff-legged derrick and a large storehouse. To this dock practically all materials and supplies for both Foundry and Indian Brook siphons were brought on lighters and unloaded by the derrick,

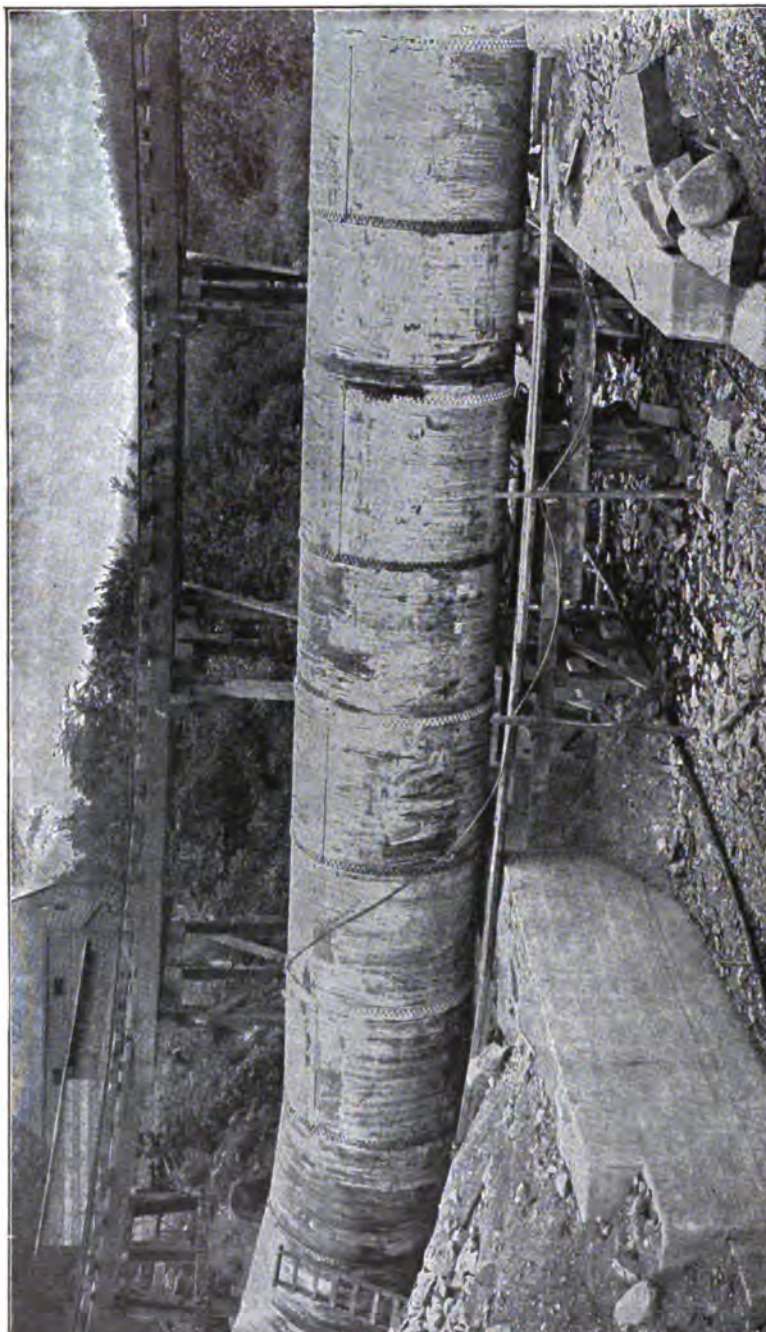


PLATE 149.—Contract 62. Steel Pipe Spanning Foundry Brook.

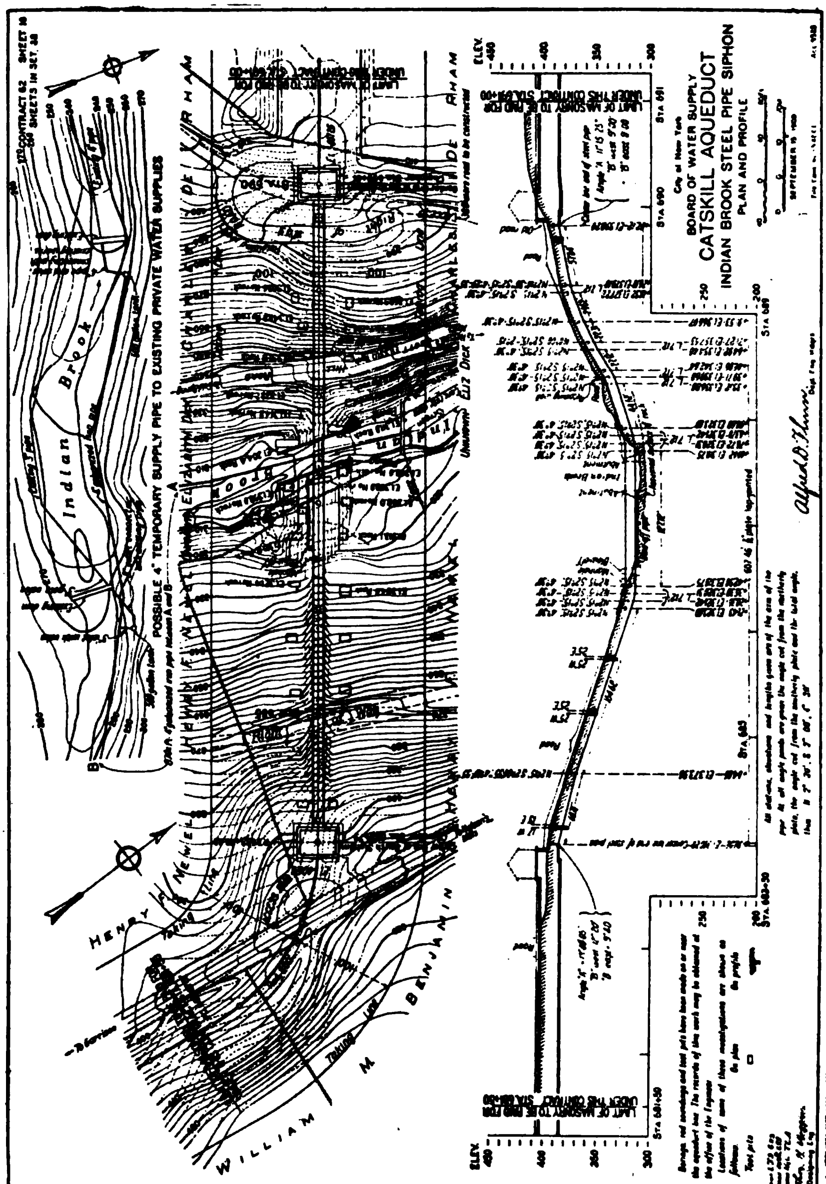


PLATE 150.—Contract 62. Indian Brook Steel Pipe Siphon. Plan and profile as given in contract drawings.

and either stored or placed on trucks. Coal was removed from the barges by clam-shell grab buckets. For the transportation of the steel pipes and cement a large motor truck was used to great advantage. A 15-foot length of steel pipe weighing about 5 tons was placed directly on the truck by the derrick unloading the scow and carried to Indian Brook, about 4 miles distant, up one hill of over 15 per cent, and unloaded by a cableway, the round trip from the dock to the place of delivery taking about one hour. The cement was loaded on the truck by the derrick in skips holding about 100 bags and unloaded by cableway which landed them at the mixer shed. The motor truck proved to be efficient and economical even under the unfavorable conditions at Cold Spring.

Plant at Indian Brook. The work at Indian Brook, although consisting of the construction of less than 1000 feet of aqueduct, value about $100,000, represents many types of construction placed in an unfavorable location. The gorge is 110 feet deep, is crossed by two public roads, and a portion of the bank has a slope of over 62 per cent. The main plant consisted of the following: Mead-Morrison cableway of 800-foot span, which covered all the siphon portion of the work; a stiff-legged derrick with 70-foot boom used at the brook crossing and at the siphon chambers; a concrete plant consisting of a Champion crusher and Chain Belt mixer. Power was supplied by four boilers, which operated the mixer, the crusher, the small compressor for pipe riveting, the pumps and the cableway.

Stream Diversion. Intakes for several domestic water supplies were located downstream from the crossing, making it necessary to prevent pollution during construction. A small concrete dam was built 75 feet above the pipe crossing, and about 1800 feet of 4-inch pipe was laid downstream to connect the private intakes with this dam. This dam also acted as a headworks to divert the stream into a temporary flume to carry the brook during the construction of the abutments at the pipe crossing.

Excavation in Rock and Earth. To remove a small ledge, Ingersoll drills were used. It was attempted to excavate the remaining material, glacial drift, by means of a $1\frac{1}{2}$-yard orange-peel bucket operated at the cableway, but this was found to be inefficient and hand excavation was resorted to. The spoil from the lighter cuts was cast up on the sides and that from the deeper ones was shoveled into buckets and transported by cableway and derricks to storage piles. No timbering was used in the trench and except in the excavation for the abutments no water was encountered. On account of the steep slopes the pipe trench excavation was carried only to the

PLATE 151.—Contract 62. Indian Brook Siphon. Excavation of trench for pipe on steep side hill using cableway and grab bracket.

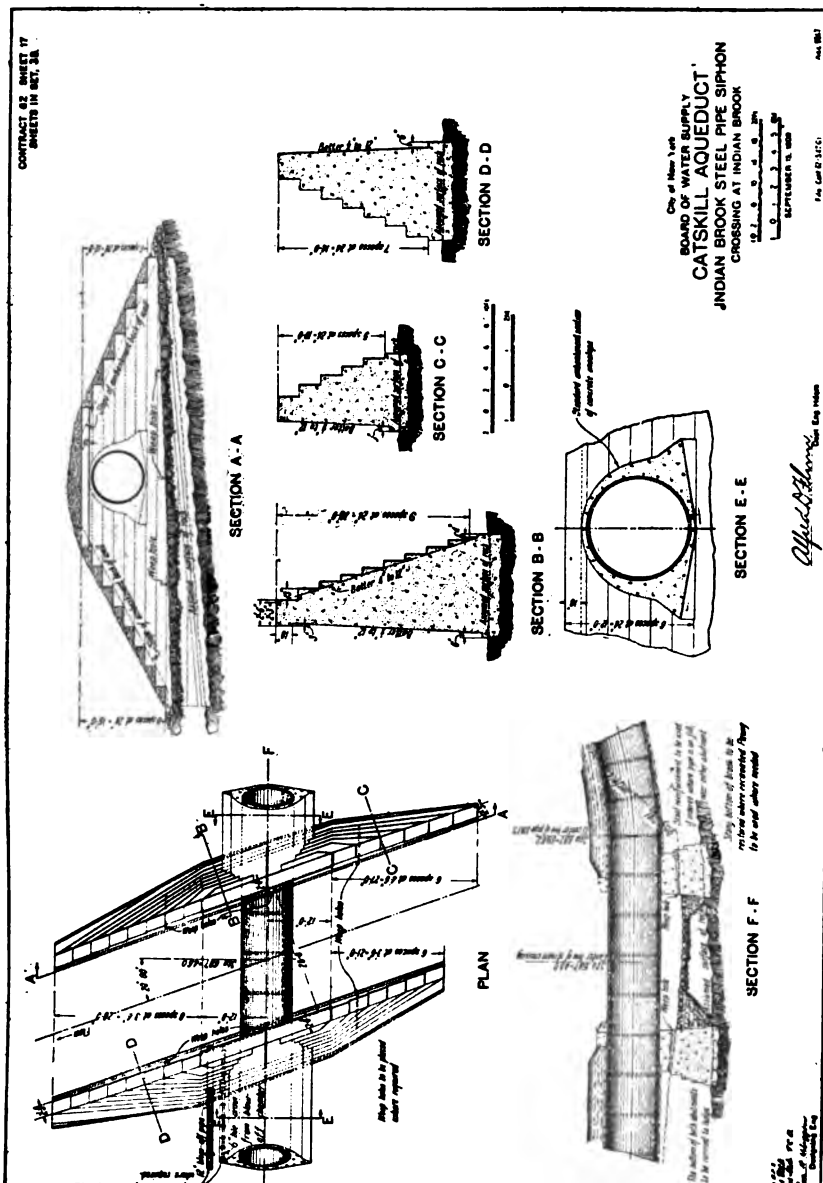


PLATE 152.—Contract 62. Indian Brook Steel Pipe Siphon. Method of crossing brook with pipe.

level of the bottom of the pipe, and transverse dikes of earth were necessary at frequent intervals to prevent erosion during storms. Just before concreting the cradle blocks, the final excavation of 6 to 8 inches was made for them, and when pipe-laying began, transverse trenches 1 foot deep by 2 feet wide were dug at the joints to give room for riveting and caulking. At the brook two retaining walls about 18 feet high were built parallel to the stream for a length of about 80 feet. The steel pipe was supported by these walls with the bottom 5 feet above the stream, giving ample area for flood waters. At this point a small valve allows the siphon to be emptied.

How Pipes were Made Up. The 15-foot lengths of pipe consisted of 2 sheets riveted together in the shop with transverse joints $7\frac{1}{2}$ feet apart. All seams were single riveted except those within 100 feet of the brook, which were double lap riveted with plates $\frac{7}{16}$ inch thick. The plates were not painted, and after being inspected at the shop were given a coat of whitewash before shipping, but this did not prove very lasting. No paint was put on the pipes, as it was desired to get the best possible contact of the concrete with the steel.

Concrete Cradle Blocks. Previous to laying the pipe, concrete cradle blocks 3 feet along the axis of the pipe, $3\frac{1}{2}$ feet wide and 6 inches deep were built at $7\frac{1}{2}$-foot intervals midway between riveted joints. The tops of these were carefully finished to a surface of a little larger radius than the bottom of the pipe, and slightly lower than the theoretical grade, in order to obviate the necessity of cutting them if the pipe ran a little low. The increase of radius was to allow the use of wedges and to facilitate cleaning between blocks and the pipe. On steep slopes care was taken to hold the blocks in place by struts and prevent them from being undermined by water. By some it is thought that narrower blocks not less than 1 foot thick would be better, especially in loose ground, where the excavation of the bell or joint holes tends to undermine them. Narrower blocks prevent an uneven bearing of the pipe, which is apt to break the thinner blocks. It is very essential that the top surface be finished off to the longitudinal slope of the pipe.

Laying of Pipes. The lengths of pipe were carried by the cableway from the motor truck to their approximate position in the trench, a few lengths in addition being stored at the sides. The first lengths were bolted in place at the brook crossing on trestle bents between the abutments, after which the pipes were laid uphill in both directions. The workmanship of the pipes was good, but the beveled ends gave some trouble. A foreman, 5 fitters and 3 helpers averaged four or five 15-foot lengths set and bolted up per eight-hour shift. The pipes followed the theoretical line and grade very closely, tending to keep a little high, the joints being a little downhill from their expected positions, losing about 1 inch in 100 feet.

Pipe Riveting. Riveting was done by compressed-air hammer, working inside the pipe. A heavy flat faced-hammer was used for "holding up" and portable coal forges for heating the rivets, all

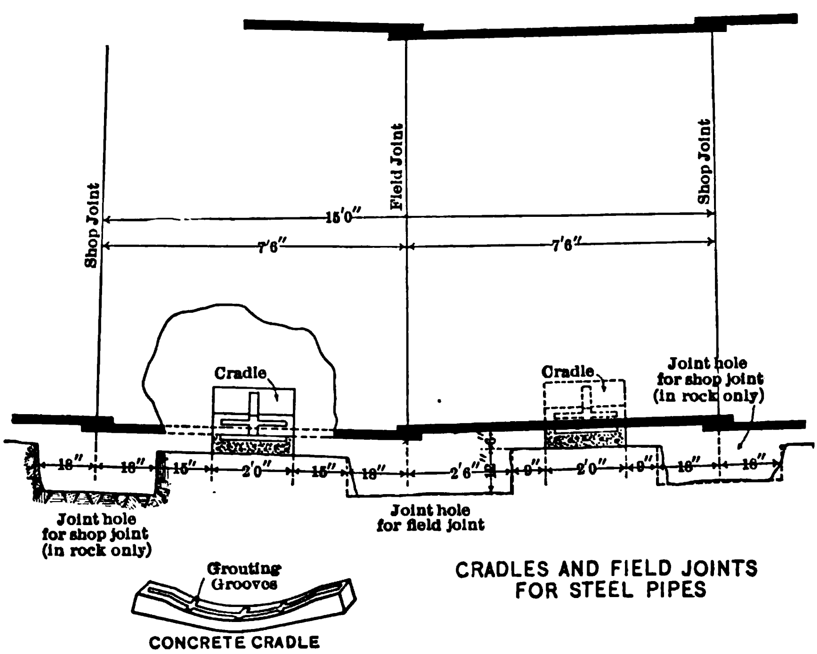


PLATE 153.—Method of Constructing Concrete Cradles and Excavating Trenches for Field Joints. Contract 68.

of which were 1 inch in diameter. About 350 rivets were driven in a day of eight hours by a gang of 8 men, 5 riveting and 3 bolting. Very thorough work was necessary, and no attempt was made to speed up. Bolts were kept within two or three holes of the new rivets and a large number in each joint were used.

Hydrostatic Test. Immediately after riveting, all seams were carefully caulked with air-driven tools. After fitting up a temporary blow-off valve and filling the spaces between the bottom of the pipes and the top of the cradle blocks with mortar, the ends of the pipes were closed by wooden bulkheads and water pumped in to test the joints under the working pressure. A few of the field joints and longitudinal shop joints showed a slight leakage, but a little caulking stopped most of this. The greatest leakage from any joint was one-half gallon in twenty-four hours.

Concreting. The concrete work at Indian Brook comprised the building of siphon chambers at each end of the steel pipe, a stretch of cut-and-cover aqueduct at each siphon chamber with transition sections between, and the outside concrete cover and inside 2-inch mortar lining of the steel pipes; also the building of abutment walls at the brook supporting a length of pipe below which the stream flowed.

A jaw crusher was fed with field stones hauled by teams and so located that the crushed stone fell into a pile just above the ½-yard chain-belt mixer located about one-half way down the south slope. Sand was supplied from a near-by bank by teams. Cement was hauled by motor trucks from Cold Spring and delivered to cement shed at the mixer by cableway. The mixed concrete was delivered into place by the cableway or to derricks located at abutments and gate chambers. The average output was 20 batches of concrete per hour, mixed 1:2:4 for certain parts of the gate chamber and 1:3:5 for the abutments.

The facing of the exposed portions of the gate chambers was a 2-inch layer of mortar, containing ½ inch crushed pink granite placed against the forms and backed by ordinary concrete. Some time after the forms were removed, the outer layer of cement was tooled off and the pink granite exposed to give a warm appearance to the finish of the chambers, which was formed into wide courses with much relief. See Plate 158.

Concrete Cover and Forms. The pipe cover was placed in two portions. First the lower half was placed to mid-diameter of pipe, using no forms in the rock trench and a single wooden panel in the earth trench. The upper form was of steel, consisting of ribs 5 feet center to center with steel connecting plates. At changes of slope V-shaped wooden fillers were necessary. The forms, several panels at a time, were easily moved by cableway. Lengths from 10 to 30 feet were concreted at one time.

For the cut-and-cover aqueduct steel Blaw forms were used with improvements suggested by the contractors. They were specially rigid and were readily moved by steel carriages. The cut-and-cover aqueduct was concreted in 15-foot lengths, but was done incidentally to the other work when the force was not busy elsewhere.

PLATE 154.—Contract 68. Placing Outer-lining of Steel Pipe Siphon. Outside forms, steel ribs with wooden lagging. Concreting done while pipe is filled with water under working pressure.

Chamber Forms. The gate or siphon chambers were especially complicated, and special forms were built in a mill at Cold Spring. They were built in units easily handled and with the use of fillers and special pieces could be made to fit several chambers. The panels were built of 2-inch tongue-and-groove planks placed on one side and supported by 2″×8″ studs. Each panel was beveled to facilitate removal after concreting, and was also provided with lifting rings and painted. The largest panel was 21′×4′. The forms were not covered with sheet iron as is sometimes required. This, in the writer's opinion, is poor practice, as the inevitable warping of the wooden forms creases and wrinkles up the metal lining to the detriment of the finish, and particularly the joints. Forms should either be all wood or all metal. Each siphon chamber required about 1000 yards of concrete and in it was bedded large amounts of reinforcing steel and bolts for gate valves. The forms were moved from the south chamber, set up in the opposite chamber and concreted in six weeks, a very satisfactory showing considering the complexity of the work. It is stated that with careful handling and housing the forms could be used five to six times.

Laboratory Tests. Laboratory tests were made before letting of the steel pipe contracts to determine the effectiveness of mortar as a protection for steel. Steel plates were cleaned by pickling and emery cloth, and covered with mortar slabs. Another set of plates similarly treated was covered with a slab of cement not in contact with the steel but separated by two metal strips, about .04 of an inch thick. These two sets of plates were placed in a tank of Croton water together with other unprotected plates and were examined two years later. The unprotected plates showed heavy corrosion. The plates covered directly with mortar were perfectly protected; those protected by cement slabs separated from the plates by .04 inch were rusted to a very slight extent, showing that they were well protected, probably due to the neutralization of any acid in the water film by the lime of the cement.

Mortar Lining. The placing of the 2-inch mortar lining inside the steel pipe presented some novel problems, as Indian Brook siphon was the first place where this was attempted. It was soon found that the pipes when filled with water, as described, did not come to a true circle, the maximum shortening of the vertical diameters being about 6 inches. This occurred at the end near the gate chamber, where the water acted as a dead load, not being under enough pressure to straighten out the pipe. In general, the differences of diameter varied inversely with the head on the pipe. This fact was

PLATE 155.—Contract 62 or 68. Junction of Cut-and-cover Aqueduct and Steel Pipe Siphon. Central pipe laid and flow into it controlled by sluice gate. Side opening for future outside pipes bulkheaded off.

apparently overlooked by the builders of the first steel forms delivered for the purpose of lining the inside of the pipes. This form rested on a steel carriage running on a track with curved steel ties. It was intended to cover the upper half of the pipe from about 6 inches below springing line. It was a total failure, due to variability of the pipe, and shortly after being set up was removed.

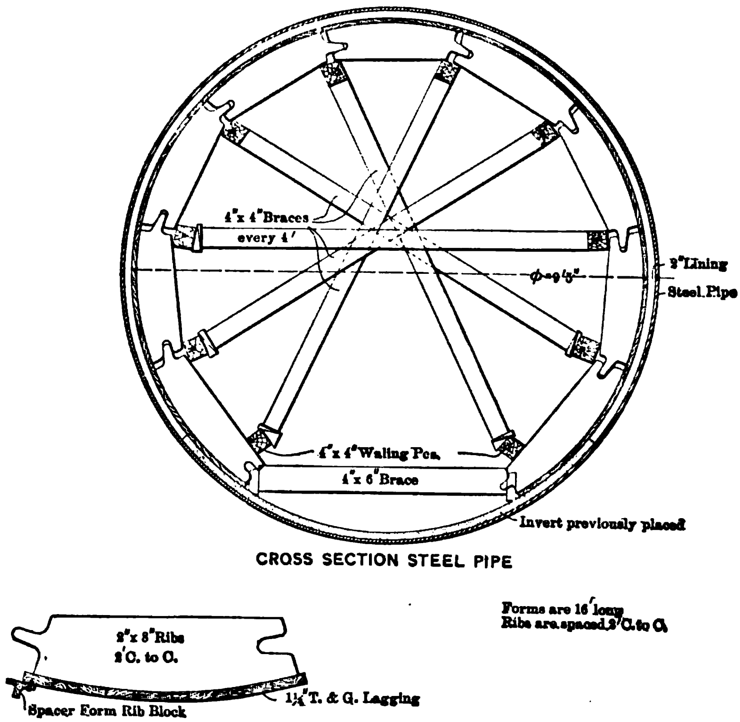


PLATE 156.—Details of Wooden Form Used for 2-in. Mortar Lining for Steel Pipe Siphons. As improved on Contract 68.

Mortar Lining Forms. The successful method used was to place an invert 8 feet wide at the bottom of the pipe, using a 1:2 mortar and finishing with screed board and trowel. Overlapping the invert was placed a wooden form built up of curved panels 8 or 16 feet long and about 2 feet wide. These panels were constructed of $\frac{7}{8}$-inch tongue-and-groove lagging laid horizontally and supported by 2-inch vertical ribs spaced about 2 feet apart. These ribs were cut so as to form where the panels were fitted together a sort of socket or knuckle-and-groove joint. A series of these panels would be wedged together to completely cover the pipe with the exception of about 6 feet of invert. Longitudinal stringers were placed at the joints in the panel ribs and braced together by diameter pieces. To keep the panels 2 inches from the inside of the steel shell small tapered castings 2 inches or 2½ inches high were screwed at frequent intervals to the lagging previously to placing the form. The form as described is shown on Plate 156. It proved to be very successful, and adjustable to varying shape of the pipe. With the exception of the lining placed by the cement gun, this form, or a modification of it, was used for lining all the steel pipes of the Catskill Aqueduct north of the City line.

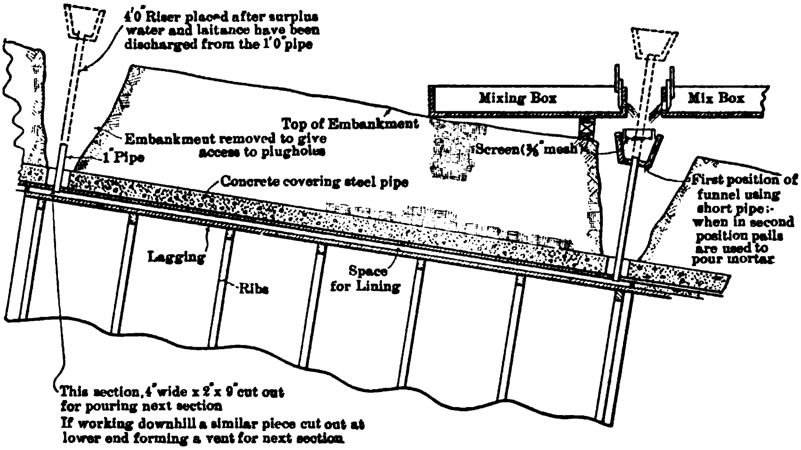


PLATE 157.—Method of Grouting 2-in. Mortar Lining for Steel Pipe Siphons. Contract 68.

Grouting Lining. The forms were grouted through vertical 2-inch pipes screwed to the top of the pipes at 15-foot intervals, one pipe being used to grout a 15-foot section and the next for a vent. The grout was mixed by hand to a creamy consistency in a duplex box arranged so that one batch would be mixed while the other was discharged. During pouring the form was constantly tapped to release the air and constant vigilance was necessary to stop numerous small leaks which opened up. There was a tendency to underestimate the bracing necessary and toward the end, double the original amount was used.

About sixteen 1-bag batches of 1:1 mixture and twenty-four 1-bag batches of 1:2 mixture were required for grouting a 15-foot section, the richer mixture being used below the springing line.

With three sets of forms it was generally possible to pour a 15-foot section every working day or 90 feet a week.

Probable Results from Lining Pipe. The resulting mortar lining was very smooth and satisfactory, the methods originated at Indian Brook being generally used elsewhere. The lining, due to temperature changes, now show numerous small cracks, particularly at the exposed crossing of the brook, sounding showing some separation of the lining from the pipe, but this is supposed to be very small. Time only will tell whether the expectation of permanency of this lining will be realized. If so, this will constitute a distinct advance in this style of construction, as not only will the rather rapid corrosion usual in steel pipes be avoided, but the flow through the pipe will remain high due to the permanent smoothness of the lining.

Sprout Brook Siphon. This siphon is located 1 mile north of the Peekskill siphon, is 2400 feet long and is under about 200 feet head. It was constructed in 1911, and the usual methods were used. One feature of this work was laying the pipe with a derrick equipped with an 80-foot boom. The excavation was accomplished by pick and shovel, wheelbarrows and teams.

Peekskill Creek Siphon. The Peekskill pipe siphon crosses Peekskill Creek 3 miles above its mouth. It is the longest pipe siphon and the one under the greatest head. The hydraulic grade at this point is about 390 feet. Peekskill Creek flows at elevation about 50, and the pipe depressed below its bottom, is under a head of about 350 feet. The pipe is built of plates varying from $\frac{7}{16}$ to $\frac{3}{4}$ inch in thickness. The lighter plates are lap riveted, the heaviest plates triple riveted with inside and outside butt straps, $10\frac{3}{8}$ inches and $16\frac{5}{8}$ inches wide. Four rows of rivets penetrate all three plates, on 3.58-inch pitch, the two outer rows penetrate the plates and inside strap on 7.16-inch pitch. See Plate 162.

Excavation. The slope at the north of the creek is very steep, with trench in earth and shale. South of Peekskill Creek the slopes are not excessive with the exception of a short stretch. The trench is here in glacial drift consisting in places of excellent sand and gravel and in places of earth and boulders. For the excavation a long-boom 35-ton Vulcan steam shovel was used, depositing material alongside the trench. Some hand excavation was also done. A diversion channel for Peekskill Creek 300 feet long and 15 feet wide at the bottom was excavated by means of drag scrapers. The pipe trench at the creek crossing was excavated with pick and shovel and with steam drills where the rock outcrops.

Laying Pipe. The steel pipe was hauled from Peekskill dock by automobile truck and lowered by steam hoists or gravity in 15-foot lengths, on flat cars. For laying the pipes, a cable-way, stationary derrick and a traveling A-frame derrick were used. Between April 11, and September 21, 1911, all except 60 feet of the pipe was laid, riveted and partially caulked.

Concreting. For concreting around the pipe, the steel forms previously used at other siphons in this contract were employed; also wooden forms with steel ribs. A considerable portion of the concrete placed around the pipe was mixed by hand on platforms set above the forms and shoveled directly into place, and all outside concrete excepting cradle blocks placed in one operation. A concreting plant was erected near Peekskill Creek and used for concreting the pipe at the creek and north of the creek for north siphon chamber and for a short stretch of cut-and-cover constructed under this contract. The concrete was transported from this mixer to the form by cableway and beyond the cableway by two derricks and car on tracks. Small mixers were also set at three other points along the works. Crushed stone wasobtained from boats at Peekskill and hauled to the work on trolley cars, where it was distributed in cars hauled by a locomotive and by cables attached to winding drums. Sand was excavated from the pipe trench and cement was hauled by trolley. Back filling followed the concreting. All the work with the exception of that in connection with the creek crossing and delivery of the steel pipe was performed by Hadley Bros.

Contract 68

Location Contract 68. This contract was awarded June, 1910, to David Peoples, who soon after starting the work assigned it to the T. A. Gillespie Company. Under this contract were built seven steel pipe lines averaging in length from 700 feet to 5600 feet, and consisting of single lines of riveted steel pipe 9 feet 9 inches and 11 feet 2 inches inside diameter, lined with Portland cement mortar 2 inches thick, enveloped in concrete and covered with embankments of earth or rock. These pipes siphon are all located in the Southern Aqueduct Department.

PLATE 158.—Superstructure over Chamber for Steel Pipe Siphon.

Contract Prices. The total bid price was $1,189,557. Some of the prices are given below:

Earth excavation, cu.yd.	.60
Rock excavation, cu.yd.	2.50
Refill, cu.yd.	0.32
9'9" steel pipe 7/16" plate, linear foot	29.00
11'3" " " 7/16" " linear foot	33.00
11'3" " " 1/2" " (lap joints) linear foot	38.00
11'3" " " 1/2" " (long-butt joints) lin. ft.	46.00
11'3" " " 9/16" " (long-butt joints) lin. ft.	50.00
Concrete around pipe, cu.yd.	5.25
Mortar lining, 9'9", lin.ft.	3.00
" " 11'3", lin. ft.	3.50
Portland cement, per bbl.	1.60

Estimated gross contract cost of 9 foot 9 inch pipe is $64.12 per foot, of 11 foot 3 inch pipe $74.48 per foot, of cut-and-cover $88.16 per foot.

Details of Pipes. Data concerning the seven pipe siphons of Contract 68 are given below:

Location.	Length, Feet.	Thickness of Plate and Kind of Joint.	Maximum Head, Feet.
Hunters Brook	1493	7/16" lap	110
Turkey Mountain	1510	"	92
Harlem Railroad	694	"	60
Kensico	1625	"	50
Elmsford	1490	"	68
Fort Hill	1267	"	72
Bryn Mawr	2714	"	214
	150	1/2" lap	
	2465	1/2" long seam butt jointed	
	255	9/16" long seam butt jointed	
Bryn Mawr total length	5584		

This contract comprised work from Hunters Brook north of Croton Lake to Bryn Mawr near Yonkers. Consequently the work was accomplished with isolated plants and generally with the same methods adopted on Contract 62, as previously described.

The interior lining of Hunters Brook siphon, however, was placed with the cement gun in an entirely different manner from all the others, as will be described.

Hunters Brook Siphon. This, the most northerly pipe siphon of this contract, is located on a tributary of the Croton River, a few miles from the new Croton dam. It is 1493 feet long under a maximum head of 110 feet and built of pipe 9 feet 9 inches in

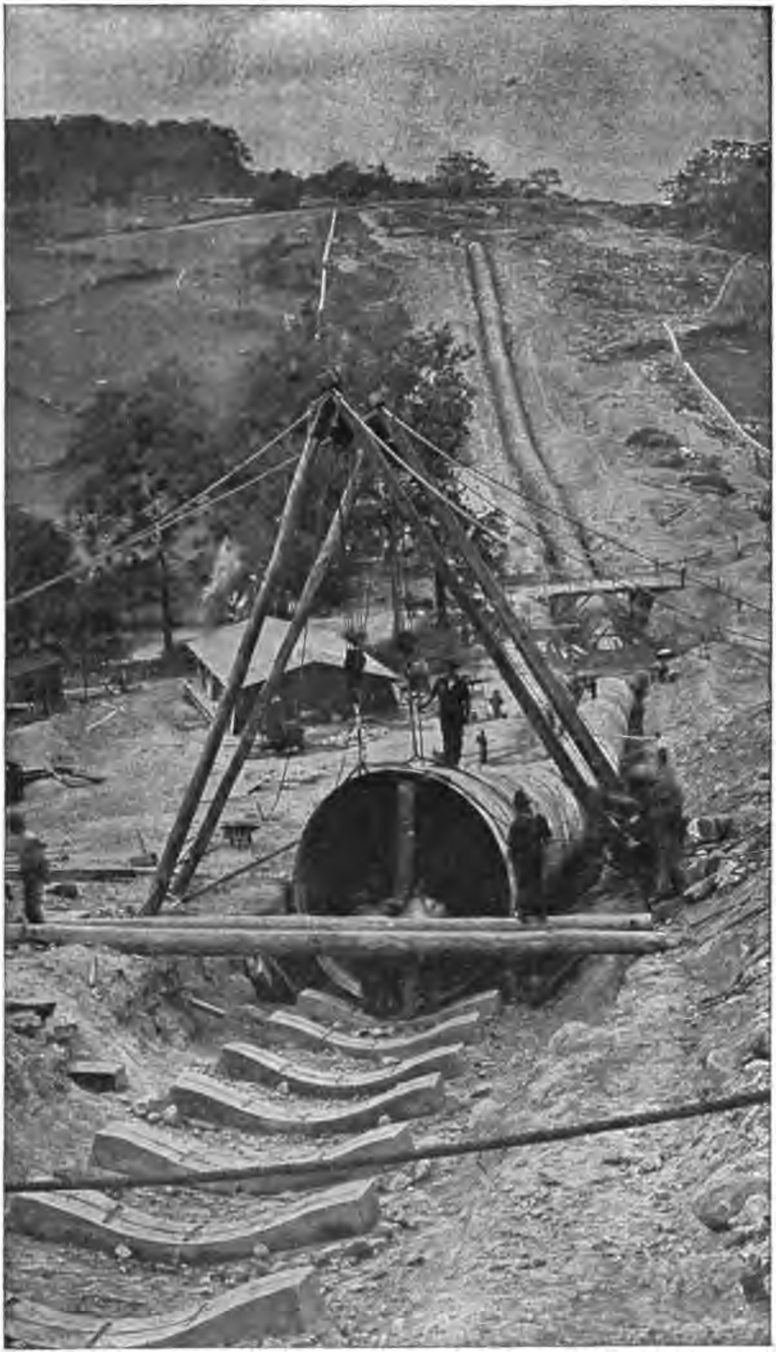


PLATE 159.—Contract 68. Hunters Brook Steel Pipe Siphon. Laying of steel pipe on concrete pedestal blocks. Later pipe was filled with water, covered with concrete and earth and lined with 2 ins. of mortar.

diameter and $\frac{7}{16}$ of an inch thick. The pipe was laid on the usual concrete cradles, which here were provided with grooves filled with grout from pipes as the outside concrete was placed, to insure a close contact between the cradles and the pipes. The pipes were placed by means of A-frame derricks, hand operated, the maximum progress being seven 15-foot sections in one eight-hour day. The steel riveting and caulking was done by hand pneumatic hammers. The pipe showed a little leakage while being tested under its working head. Steel arch ribs 5 feet apart with wooden lagging was used for outside forms. The maximum week's work on concrete covering was 223 feet.

Cement Gun for Mortar Lining. This siphon is chiefly remarkable for the manner of placing the 2-inch mortar lining. It was seen by the contractor after a test of a steel form that this would be difficult, due to the variable size of the pipe, it being found that the pipe when filled tended to flatten at the upper portions under low head, but at the central portions under the high heads tended to be nearly circular, due to the internal pressure. An apparatus known as a cement gun was exhibited during the winter of 1910–11 at the cement show, and the T. A. Gillespie Company contracted with the owner of this device for the placing of the lining at the Hunters Brook siphon, and permission was obtained from the engineers to allow its use instead of the contemplated method of grouting the lining by the use of an interior form. Previous to using the cement gun, a strip of invert 7 feet wide was laid and screeded in alternate stretches of $7\frac{1}{2}$ feet in the usual manner. The apparatus shown on Plate 160, consists of a double tank with air-tight bulkheads and a revolving feed for sand and cement. This is discharged by air under 40 pounds pressure through a rubber hose. As the mixture reaches the nozzles, it comes in contact with water discharged through a parallel hose, and the combined spray is discharged with great force against the surface to which it is being applied. The operator holds the nozzle from 2 to 3 feet from the surface being coated, moving it back and forth continuously, and controlling the flow by lever valves. The first layer placed is about $\frac{1}{2}$ inch thick, and is a rough coat to which other layers were applied.

Sand and cement were mixed dry and dumped into the upper tank and the upper bulkhead closed and the charge dropped into the lower compartment. The lower bulkhead was then closed and the pressure in the upper tank released, the revolving feed wheel feeding the mixture slowly into the discharge hose; at the nozzle the air pressure was kept at 30 pounds, and the ejected mortar

PLATE 160.—Contract 68. Hunters Brook Steel Pipe Siphon. Apparatus for mixing and placing mortar lining with "cement gun" mounted on outside lining of steel pipe. Sand and cement were placed in compartments of these machines and blown by compressed air through pipes to nozzle where water was added to form mortar coat sprayed on inside of pipe.

deposited in alternate sections. All the lining was placed between April 25 and August 12, using for part of the time two machines and two shifts, the maximum weekly progress in placing the interior lining being 254 feet.

The final shape was obtained by screeding the fresh mortar with a straightedge working against two laths placed to give proper thickness of lining. It must be admitted that the lining of a pipe is difficult for this kind of work, as considerable sand and cement rebounds, making the air in the confined space difficult to breathe. In addition, some dry material, nearly all sand, tends to accumulate near the bottom of the pipe next the invert. To make up for this an excess of sand is put in, so that the lining may be no richer than is intended. On this account the dry mixture was changed from 1:2 to 1:2½, and later to 1 cement: 3 sand, with the idea of securing a 1 to 2 mixture in the finished lining. The accumulated material which fell to the invert from the cement gun contained cement in proportion of about 1:3¾, indicating a considerable waste of cement.

It was found that mortar from the cement gun, being less well supplied with water than a grouted lining, has a greater tendency to crack, and more attention must be paid to keeping it moist. Failure to do this may be responsible for the greater amount of cracking of the lining made by the use of the cement gun. The lining placed by the cement gun, due probably to its final screeding, is very smooth, but contains many fine cracks.

When the mortar invert was placed much in advance of the arch the upper portion of the invert tended to pull away from the pipe, in extreme cases to ⅛ inch at the upper edge to nothing 18 inches down. This space was grouted before placing remainder of lining.

The work accomplished by the cement gun was considered satisfactory, but the apparatus had not been developed to an extent to compete commercially with the ordinary method and was not used subsequently. The cement gun is an apparatus which has been found very useful for placing stucco on buildings and covering steel beams, and has been used to protect the sides of cuts in rocks from the action of weather. It has been experimented with for this purpose on the Panama Canal and the Bergen Hill cut of the Erie Railroad at Jersey City.

Elmsford Siphon. The Elmsford steel pipe siphon between Tarrytown and White Plains is 1774 feet long. It crosses a depression about 70 feet below hydraulic grade. The unit length of pipe is 7½ feet and is made up of two steel plates lapped 3¼ inches with single-riveted joints, with 2½-inch pitch. Two such pipes are shop-riveted together and shipped to the work in 15-foot lengths, the ends having the holes punched for field riveting to the next length.

Laying of the Pipes. After the trench, excavated by ordinary methods, the material being cast to one side, was completed, the concrete cradles, 3 feet wide, 6 to 10 inches deep and 11 feet long, were cast in the bottom of the trench on 7½-foot centers midway between the riveted joints. The pipes were then set by a guy derrick on these cradles, which have the same curvature as the bottom of pipe. At the field-riveted joints, 15 feet apart, a cross-trench 3½ feet wide and 18 inches deep was dug, to allow working room underneath the pipe for the riveting. The pipes were riveted by pneumatic hammers operated by a small compressor. The ends of the overlapping plates were then pneumatically caulked by upsetting and driving the lower part of the overlapping plates against the plate underneath as much as ⅛ to ⅛ inch. The pipes were then bulkheaded at both ends and filled with water to the hydraulic grade of the Catskill Aqueduct. This pressure was maintained by pumping into a riser pipe located at one of the bulkheads and maintaining the elevation in this pipe constant. The pipes and rivets were then caulked by hand where leaks showed. This leakage was found to be very small, the pumpage into the siphon being merely that necessary to compensate for leakage at the bulkhead.

Covering Pipe. After filling the pipe with water the space between the cradles and the pipe was grouted by pouring grout into 2-inch grooves cast in the cradle to insure complete contact of cradle and pipe. The cradles were sufficiently strong to support the pipe. The forms were then placed outside the pipes, consisting of arched angle-iron ribs with wooden lagging and steel bulk-heads. The angle irons were joined over the top of the pipe, and, in addition, supported a horizontal channel-steel tie for the track over the pipe along which cars were run. The ribs were well braced by wooden struts to the ground. The lagging was made with shiplap joint, and put in place between the ribs as fast as the concrete rose in the form. This made a simple and very satisfactory form for this purpose. It would be difficult to adjust a steel panel form, such as is used on the cut-and-cover aqueduct, to the varying grades and the vertical and horizontal curves of the steel pipes.

Change of Shape in Pipe when Full of Water. As specified for all the steel-pipe siphons the concreting was done while the pipe was filled with water, the purposes being to hold the pipe in the shape that it will finally assume, so that when the mortar lining is placed no change in shape will occur after the water is again admitted. It was found that the pipes flattened a good deal under their own and the water load, so that there was a considerable difference between the vertical and horizontal diameters, as much as 6 inches. The pressure of the water contained in the pipe is not sufficient to bring it to its circular shape, although it is more effective at the higher heads, but it made the pipe very solid and stable during the placing of the concrete. The shape of the pipe when filled with water is a resultant of the dead load and the internal pressure of the water. At high heads the pipe comes to a nearly circular shape.

Concreting of Elmsford Siphon. The material for the concrete was received from the Pittsburgh Contracting Company's railroad, which reached the north end of the pipe line. The concrete was hauled from the mixer in Koppel side-dump cars, pushed along a narrow- auge track by man power or up inclines by a cable operated by steam hoist, and dumped directly into the forms. A 30-foot section of all the outside concrete, except the cradles, was placed in two shifts, so as to form a monolith. A part of the material excavated in the trench was decomposed schist which was readily drilled by steam drills operated from a 40-H.P. boiler, this boiler also supplying power for a derrick which lifted skips of excavated rock to the sides of the trench, later used for back-filling. After the complete concrete envelope was placed and back-filled the water under pressure inside was drawn off and the interior 2-inch mortar lining grouted as previously described.

Bryn Mawr Siphon and Triple Portal of Yonkers Siphon. North of Hillview reservoir there is a depression of about 3.3 miles. Originally it was supposed that this would be passed by means of a pressure tunnel, with the usual downtake, uptake and drainage shafts. Exploration by core drills showed that the lower two-thirds adjacent to the Hillview Reservoir would be in Yonkers gneiss of very good quality. North of this, underlying the valley of Sprain Brook, was found a belt of decomposed limestone extending to a great depth. For this reason it was decided to adopt an unique construction. For the northern portion of the depression a steel-pipe siphon, 11 foot 3-inch pipe, was used. The lower portion was tunneled in the usual manner for pressure tunnels, but it has at the north end in the side hill a triple portal joined 275 feet back to form the single 16-foot 7-inch circular tunnel of the Yonkers pressure tunnel. The three tunnels at the portals are excavated to enable 175 feet of the

PLATE 161.—Contract 68. Hauling Steel Pipe to Site of Work, Using Horses.

steel pipes of the Byrn Mawr siphon to be securely concreted in. At present only the central steel pipe will be laid, the two side tunnels being bulkheaded off. From the north portal of the Yonkers tunnel the steel pipe extends a distance of 1.1 miles to its siphon chamber at hydraulic grade, and is the longest pipe siphon in the Southern Aqueduct Department. It was laid under Contract 68, by T. A. Gillespie Company. Included in this work is a blow-off chamber for draining not only this siphon, but several miles of the adjacent aqueduct on the north and the Yonkers pressure tunnel on the south. In addition there is another 12-inch blow-off and a drain for the chamber connecting with the Yonkers pressure tunnel.

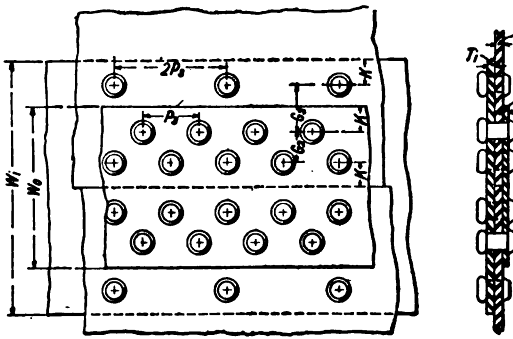
Earth Excavation and Foundations. Earth was generally removed by the use of horses, slip scrapers and by hand. For the deep trench north and south of the Sprain Brook, a traveling stiff-legged derrick with 35-foot boom operated on broad gauge track alongside the trench, the material being loaded by hand into 1-yard buckets. The rock excavation was accomplished by ordinary methods, using steam drills. Soon after the concrete envelope for the pipe was placed, the earth removed was put back as embankment. Some of the pipe was founded upon embankment made and rolled in the usual manner. In two stretches of a few hundred feet, water-bearing sand and gravel were found in the trench. For a foundation a timbered platform was used, and the trench was drained by a box drain. The trench bottom was excavated to subgrade with transverse slopes toward the center 1 on 6 to 1 on 18. 2″×8″ longitudinal stringers were embedded in the trench bottom with either one or two thicknesses of inch boards spiked across them with their inner ends resting on the edge of the 6″×8″ box drain in the center. The drain led to a sump in the blow-off chamber excavation, from which the water was pumped to Sprain Brook. This effectively dried the bottom and provided suitable foundation for the concrete supports of the pipe. A considerable excavation had to be made for the blow-off chamber; 2-inch sheeting was driven to a depth of 22 feet by hand and supported by 8″×8″ timber sets 3 feet apart vertically. Pulsometer and centrifugal pumps handled the water, which ran as high as 800 gallons per minute.

Laying of Pipes. The pipe was supported on concrete cradles 3 feet wide, 10 feet long and 18 inches thick. These were hand mixed on the bank, the materials being supplied by wagons. Pipe sections, generally 15 feet in length, were delivered and stored alongside of the trench between November, 1910, and May, 1911. All of the 5600 feet of pipe was laid between April and September, 1911.

The pipe was rolled to position alongside the trench and lowered by ropes. For lifting and final setting in the trench a double-bent A-frame derrick was used, but the pipes were pulled together by a hoisting engine, the engine also serving to move the derrick. A portion of the line of the pipe was on such a steep grade that a 3-foot gauge track was laid parallel to the trench and the pipe sections hauled up by a hoisting engine at the top of the hill, the pipes sliding directly on the rails.

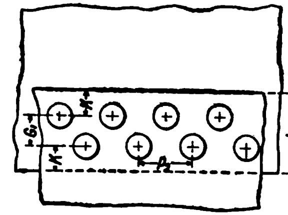
Riveting, Caulking and Testing. Riveting and caulking of seams were done by pneumatic hammers. All leaks found during the test in joints or around rivets were hand caulked. Air was furnished by a compressor of 350 cubic feet capacity. For the hydrostatic test and previous to the placing of the exterior concrete the pipe was filled with water at the full working pressure. Timber bulkheads were used, and the pipe was filled by a pipe line and pumps at Sprain Brook. A 3-inch standpipe of sufficient length to reach the hydraulic gradient was erected near the upper bulkhead, and the required pressure maintained throughout the work by sufficient pumping to produce a small overflow from the standpipe. The Crosby pressure recorder was attached to the pipe at a point where the pressure was 72 pounds. This afforded a check on the pumping and the maintenance of the required pressure. The upper one of the bulkheads leaked very little and the other less than 10 gallons per minute, although it had to sustain a pressure of about 530 tons. It was substantially built of timber 18 inches in thickness. An intermediate bulkhead used in concreting the northerly third of the siphon leaked at the rate of 30 gallons per minute.

Concreting around Pipe. The principal mixing plant contained a 1-yard Smith mixer which discharged directly into the buckets or dump cars. This plant was served by a 1300-foot Mundy cableway which delivered broken stone obtained at the north portal of the Yonkers tunnel. Sand was obtained from the trench in adjacent city property near the mixing plant. From the mixing plant a 3-foot gauge track extended from the mixer to the northern end of the work and southward to the blow-off chamber. Along this track concrete was delivered in two-car trains carrying four 1-yard bottom-dumping buckets hauled by locomotives assisted by hoisting engines on the steep grades. The buckets were dumped into the forms by traveling derricks. At places too steep for the operation of the derrick, side-dumping cars were used and the concrete shoveled from portable platforms at the sides of the tracks, into the forms. South of the blow-off chamber mixing was done in a three-quarter



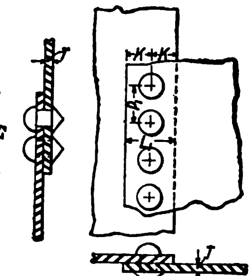
LONGITUDINAL SEAM - TRIPLE-RIVETED BUTT

Thickness of shell	Longitudinal seam								
	Pitch of rivets		Gage distance		Edge distance	Width of cover plates		Thickness of cover plates	
	Inner rows	Outer rows	Inner rows	Outer rows		Outer	Inner	Outer	Inner
T	P_3	$2P_3$	G_2	G_3	K	W_o	W_i	T_o	T_i
1/2"	3.58"	7.16"	1 13/16"	3 1/8"	1 5/8"	10 3/4"	16 3/4"	7/16"	9/16"
9/16"	4.00"	8.00"	2 1/16"	3 1/8"	1 5/8"	10 3/4"	16 3/4"	1/2"	5/8"
11/16"	3.82"	7.64"	2 1/16"	3 1/8"	1 5/8"	10 3/4"	16 3/4"	1/2"	5/8"
3/4"	3.58"	7.16"	1 13/16"	3 1/8"	1 5/8"	10 3/4"	16 3/4"	1/2"	5/8"

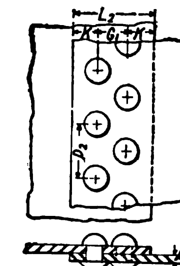


LONGITUDINAL SEAM
DOUBLE - RIVETED LAP

Thickness of shell	Longitudinal seam			
	Pitch of rivets	Gage distance	Edge distance	Lap
T	P_2	G_1	K	L_2
7/16"	3.50"	1 13/16"	1 5/8"	5 3/16"
1/2"	3.11"	2"	1 5/8"	5 1/4"



SINGLE - RIVETED LAP



DOUBLE - RIVETED LAP

CIRCULAR SEAM

Thickness of shell	Edge distance	Single riveted			Double riveted			
		Number of rivets	Approx. pitch	Lap	No. of rivets each row	Approx. pitch	Gage distance	Lap
T	K		P_1	L_1		P_2	G_1	L_2
7/16"	1 5/8"	144	2.5"	3 1/4"	←103	3.50"	1 13/16"	5 3/16"
1/2"	1 5/8"	not used			116	3.11"	2"	5 1/4"
9/16"	1 5/8"	"	"		123	2.85"	2 1/16"	5 5/16"
11/16"	1 5/8"	"	"		139	2.61"	2 3/16"	5 7/16"
3/4"	1 5/8"	"	"		145	2.50"	2 3/16"	5 7/16"

Double riveted joint with 7/16" plate is for use only at and 100' either side of the stream crossings at Indian brook and Tongore creek.

Assumed tensile stress on net section of plate 15000 lbs. per sq. in.
" bearing " " rivets and plate 22500 " " " "
" shearing " " plate 10000 " " " "
" " " " rivets-single 9000 " " " "
" " " " " double 8000 " " " "
All rivets 1 inch in diameter before driving
All computations based on diameter of driven rivet = 1 1/16"

All pipe to have alternate inside and outside courses, i.e. not to taper

PLATE 162.—Steel Pipe Siphon. Longitudinal and circular joints. Details of rivet spacing, splice plates, etc.

cubic yard Smith mixer. Broken stone was obtained from the Yonkers tunnel and sand delivered by a cableway. The mixer discharged directly into bottom-dumping cars, operated on a track laid on top of the pipe, lowered into place by a cable hoist. The concrete was discharged from the cars directly onto the pipe. Bottom-dumping cars running on short stretches of track directly on top of the pipe were also used at other points which could not conveniently be reached by the derrick car, which filled the cars from the buckets operated on the track alongside the trench.

Forms. The forms were the usual steel ribs supporting wooden shiplap lagging, placed as the concrete rose in the forms. The entire stretch of outside concrete was completed between August and December, 1911, a total of about 10,000 cubic yards. The interior 2-inch mortar lining was placed during 1912 by the use of the usual interior forms and grouting method.

CHAPTER XIV

CROTON DIVISION CUT-AND-COVER AQUEDUCT AND GRADE TUNNELS

Contract 23

Work and Prices. This contract, comprising the northerly 2.2 miles of the Southern Aqueduct Department, was awarded March, 1909, to the Glyndon Contracting Company, the total contract price being $1,109,102. Some of the unit prices are given below:

Open-cut excavation per cu.yd.	$0.35 to .65
Refill per cu.yd.	.23 to .50
Excavation in tunnel per cu.yd.	6.75
Timbering in tunnel per M.	45 temporary 60 permanent
Concrete in open cut per cu. yd.	5.25
Concrete in tunnel per cu.yd.	5.75
Portland cement per bbl.	1.90
Forms for lining in tunnel per ft.	2.75
Medical and surgical practitioners per month for 42 months	125.00
Sanitary services per month for 42 months	200.00

On the basis of contract quantities the linear foot cost of cut-and-cover is $67.50; of grade tunnel, $114.96.

The last two items were for the purpose of compensating contractors for special precautions to prevent pollution of the neighboring Croton Lake, which lies just south of this work. It was required that all organic matter be incinerated and water from the camps or even from the tunnels be filtered or sterilized. The contract consists of Scribner grade tunnel, 300 feet long; Hunters Brook tunnel, 6150 feet long; and three adjacent stretches of cut-and-cover, 200 feet, 2600 feet and 2650 feet long respectively.

Power Plant. A large central power plant was constructed between the two tunnels and consisted of two Mosher water-tube boilers, each of two units, 150 H.P. per unit; three Ingersoll-Rand compound condensing compressors, each rated at 1400 feet of free air per minute. About 8500 feet of 5-inch pipes was laid to the north portal of Hunters Brook tunnel, and 4000 feet to the southern limit of the contract, thus providing compressed air for the entire contract. Three 30-K.W. dynamos were used to supply light for tunnel and camp. To provide water the brook was dammed and a pipe line laid to the power plant and parallel to the aqueduct. In dry weather water was obtained from a lake about 5800 feet distant from power plant.

Methods of Excavating Hunters Brook Tunnel. This contract is notable chiefly for the difficulties encountered in the construction of the Hunters Brook tunnel and the methods used to overcome them. The north tunnel portal was in soft ground, requiring extra care in excavation. At the north portal a top heading was driven for about 700 feet, being followed by the bench about 60 feet back from the face of the heading. All but about 70 feet of this was timbered. After this the bench was brought to the heading, a small bottom drift about 8×8 feet was driven about 90 feet, when it was widened to the full width of the tunnel. A platform was then built in this drift or heading and the upper half of the tunnel blown down upon it, the muck then being dropped through openings into cars on a track below. The superintendent of this work was a mining engineer who endeavored to apply Western mining methods to this tunnel, with the idea that they would result in superior speed and economy.

Bottom Heading Method. At first the bottom heading was drilled with the usual arrangement of cut holes and side rounds from columns on which were mounted Ingersoll-Rand drills. Later, a horizontal bar was substituted for the two columns and a different arrangement of holes used. The bar was set up about 3 to 4 feet above invert grade and all holes drilled from this one setting of the bar, the drills hanging from the under side of the bar for the lowest row of holes. The heading was shot, using a battery and electric fuses with the latter arrangement. When drilled from columns the holes were all loaded at once and shot with fuses about 8 feet long. Several rounds were obtained by successively shortening the fuses 2 inches, which were then touched off as fast as possible by a torch. Plate 163 indicates the order of shooting.

Taking Down Roof. The roof was shot down on a platform as shown in Plate 163. The drilling was done with two drills hung on horizontal bars 9 feet long, about 14 feet above invert grade, the men standing on the muck pile on the platform while drilling; 12 holes were shot as indicated, after which the remaining rock was drilled by Jap drills placed where needed. Mucking was done by removing part of the lagging which formed the floor of the platform and shoveling the muck into the cars beneath. This platform was placed about 80 feet back of the bottom heading and was about 120 feet in length, supported by 12″×12″ posts, capped by green tree timbers, braced to rock, 4 feet on centers. It is claimed for this method that the heading can be more quickly drilled from one setting of a horizontal bar than by several settings

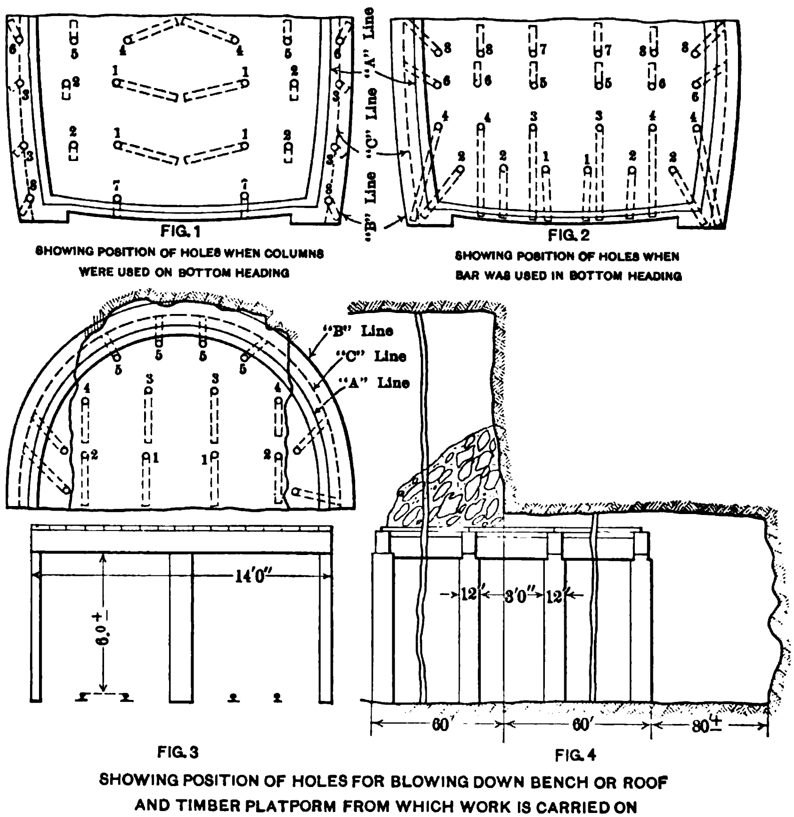


PLATE 163.—Hunters Brook Tunnel. Method of excavating tunnel with bottom heading. Method of using timber platform for upper portion of tunnel.

of columns, and that the mucking is facilitated by cutting out the usual wheeling of heading muck over the bench; also that a better tunnel section can be secured, as all the drilling is done with approximately horizontal holes.

Horizontal Bars for Mounting Drills. The results indicate that the tunnel is of an unfavorable shape for a horizontal bar, it being rather high in proportion to its width. Horizontal bars have been used for driving tunnels to great advantage where the cross-section is small, such as the drainage tunnels in the West and the small bottom headings in Switzerland. The result of using the bar here was that the holes were placed in unfavorable positions and considerable supplementary trimming was necessary.

Progress Made. The advantage gained by eliminating the wheeling of the heading muck for the usual 75 to 100 feet appears to be far outweighed by the labor involved in the repeated taking down and erecting of the shooting platform, and the unfavorable position offered by this platform for drilling the upper holes, as shown by the large amount of trimming necessary. In all, considerably more holes were drilled than by the usual method employed. The record shows but a moderate progress. The maximum monthly progress in the heading was 233 feet and 236 feet bench in the north side, and 288 heading and 278 feet bench in the south side, although during this period the monthly progress in some cases was very low due to poor ground. The average weekly progress of completed tunnel was about 32 feet.

The headings of this tunnel met in October 15, 1911, at a point 1955 feet in from the north portal, exactly two years after the beginning of the work. Since April of the same year work had been discontinued in the north heading.

Tunneling through Bad Ground. The rock in Hunters Brook tunnel had a strong tendency to break into blocks which were often separated by talc seams. At a point 1418 feet from the north portal a bad slip occurred. Blocks of rock fell from the roof and sides for several days, until it extended for a length of about 62 feet with a maximum height of 45 feet above the invert grade. After equilibrium had been restored this broken ground was tunneled through and timbered with bents of five 10″×12″ arch blocks resting on wall plates posted to the bottom of the tunnel, bents 24 inches center to center. To protect workmen on the timbering from falls of rock horizontal timbers or stalls were wedged across the side walls and above the line of permanent timbering, and the space above packed tight with cord wood. The timbers were then dry packed to a horizontal plane about 13 inches above the lagging, covered with 2 inches of mortar and the remaining space packed with stone and cord wood. Transverse wooden bulkheads were built at intervals of 30 feet extending from the lagging to the roof. These sections were grouted to the top of the dry packing.

Recovering Tunnel after Wreck of Timbering. In December, 1910, when the timbering was 1470 feet from heading a serious fall occurred, displacing five sets of timbers. These sets were blocked up and work was resumed; a small drift 6′×8′ was then driven through the broken rock of the slip. A few days later another fall occurred which wrecked nineteen sets of timbers south of a point 1440 feet from portal, including the sets first displaced. The timbering in many of these sets was badly crushed and was immediately posted up to prevent further settlement. The small drift was then excavated through the broken ground to the bottom heading previously excavated. The wrecked timbers were replaced together with many new sets. For a portion of the distance the timbers were placed back to back. Concreting was then ordered for this bad stretch, which was supported by 80 feet of lining placed in January to March, 1911. Drilling of the bottom heading was resumed February 26, and the bench March 9. The rock seemed to be improving, but the roof was seamy and treacherous, small falls of rock occurring. After excavating for a few weeks work was discontinued at a point 1955 feet from portal. Timbering was continued for a short time after this, when all work stopped in the north heading.

Disadvantages of Bottom Heading in Bad Ground. The contractor showed ability in getting by bad ground after the falls occurred, but the bottom heading method is unsuited for work of this kind, as it is not practicable to place timbering until the entire tunnel is excavated, whereas by the top-heading method the timbers can be placed soon after the poor ground is exposed. At the south portal the bottom heading was driven in 221 feet and the top then blown down. This resulted in compacting the fallen rock, so that mucking was difficult. The top-heading and bench method was continued for 819 feet in, when this method was discontinued for the bottom heading, as described heretofore. Two drilling shifts were used and two advances a day made, averaging 5 feet each. The firing was done by battery and with fuses, 60 per cent forcite being used. Three mucking shifts were employed to shovel rock into the cars, their work being aided by placing iron plates on floor of heading.

Excavation of Roof, South End. The top or roof was shot down upon a platform of heavy posts 6 feet long capped by timbers 14 feet long. These sets were spaced 4 feet apart and floored over with 3-inch planking. This platform averaged about 120 feet in length, half of it being the roof to be shot down. As the platform behind was cleared of muck sets were removed and set up ahead. To prevent the breaking of caps a third post was placed under the center of each set previous to shooting. The excavation of the top was as before described. The rock in this tunnel varied from decomposed schist to hard schist. The inflow of water into the tunnel was about 90 gallons per minute, 60 of this from the south end. The tunnel is supposed to traverse the axis of an immense fault in the Manhattan schist, which accounts for the bad ground.

Concrete Plant and Methods. The sand for the concrete was obtained from a deposit 4400 feet away and transported by a Roebling aerial tramway supported on fifteen towers 10 to 85 feet high. The crushing and concrete plant consisted of two jaw crushers operated by a 70 H.P. engine which also ran the stone and sand elevators, screens and belt conveyors for cement. A cubical mixer of 33 cubic feet capacity was operated by a 15-H.P. engine. The concreting in the grade tunnel was done with the use of 180 feet of Blaw forms by the usual method, three sets of 60-foot lengths being used and about 178 feet were concreted per week. For the cut-and-cover Ransome forms were used. Excavation of cut-and-cover trench was accomplished with the aid of a 60-ton Marion steam shovel which handled from 45 to 376 cubic yards per day. The refill was either placed directly over the arch by the shovel or into cars which were hauled and dumped over the arch by dinkies. Some later refilling was also done by a traveling derrick with clam-shell bucket.

Scribner Tunnel. This tunnel was only 300 feet long and was driven through from one end with a top heading, the bench being subsequently excavated, 50 feet of the tunnel requiring timbering.

Contract 23 was taken over by John J. Hart in 1912, who is pushing the work to completion.

Contract 24

Work and Prices. Contract 24 was let March, 1909, to the Bradley Contracting Company, for a total of $973,694. Some of the individual items are given below:

Rock excavation in shafts per cu.yd.	$13.00
Excavation of pressure tunnel, cu.yd.	6.00
Excavation of grade tunnel, cu.yd.	6.00
Concrete masonry in shafts, cu.yd.	6.00
Concrete masonry in pressure tunnel, cu.yd.	5.46
Concrete masonry in open cut, cu.yd.	5.17
Portland cement, bbl	1.70
Forms for lining shafts per foot	10.00
Forms for tunnel per foot	3.00
Open-cut excavation, cu.yd.	.60
Refill, cu.yd.	.40
Medical and surgical practitioners per month	150.00
Sanitary services, per month	300.00

This contract is only 1.2 miles long and comprises three types of construction, cut-and-cover .4 of a mile, grade tunnel .3 of a mile, and .5 of a mile pressure tunnel under Croton Lake.

Computed from contract quantities the linear foot cost of cut-and-cover is $69, of grade tunnel $119, of pressure tunnel $126, shaft $203.

Sanitation and Camp. As the aqueduct crosses the lake a short distance below the intake for the new Croton Aqueduct, this contract contains stringent sanitary provisions. Before any construction work could be done, camps had to be established, fenced and furnished with sanitary equipment. Camp Bradley was located near the aqueduct on private land 140 feet above the lake. It consisted of sixteen buildings, including incinerators, the buildings being heated by steam, lighted by electricity and supplied with water from the lake. A sewer system collected the wash water from the camp and discharged it into a filter bed, and the rain water from the camp area was led by ditches to a settling basin and then to the filters. Four incinerators were in operation at the camp and were used daily for the burning of all organic matter, including garbage. At the north portal of the Turkey Mountain tunnel rain-water run-off from the spoil bank was collected in a settling basin from which the water seeped into the ground, and the tunnel drainage pumped into a settling basin. At the south portal of the Turkey Mountain tunnel and the downtake shaft of the Croton Lake pressure tunnel, the tunnel drainage and the spoil-bank run-off were collected in a settling basin and then discharged onto sand filters. The same provision was made at the uptake shaft. Ditches were constructed around the camp, which was sewered, and all drainage water led to sand filters, the effluent from which was also dosed with hypochlorate of lime, as was also done at the other filters.

Croton Lake Siphon. The Croton Lake siphon is a pressure tunnel similar to that of the Rondout and Wallkill, but it is the shortest on the line of the Catskill Aqueduct. It was constructed in sound Manhattan schist about 350 feet below high water in the lake. The downtake shaft (Plate 167) is very important and was constructed so as to discharge, through a blow-off conduit into Croton Lake, the full capacity of the Catskill Aqueduct, or any portion desired to reinforce the Croton supply. The difference in elevation at this point between the hydraulic grade of the Catskill Aqueduct and high water in Croton Lake is about 160 feet. This head, of course, will be wasted by discharging into Croton Lake.

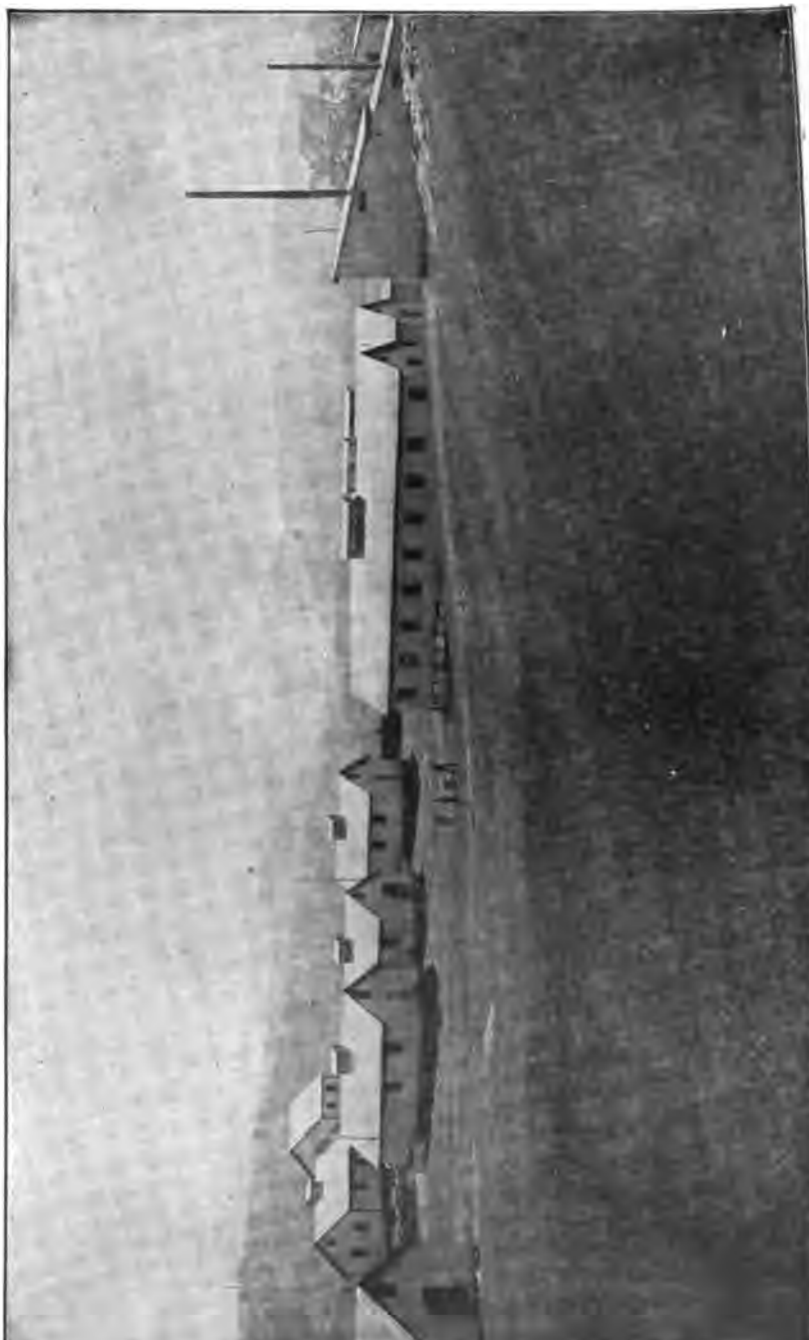


PLATE 164.—General View of Camp Bradley at Croton Lake. Incinerator at right.

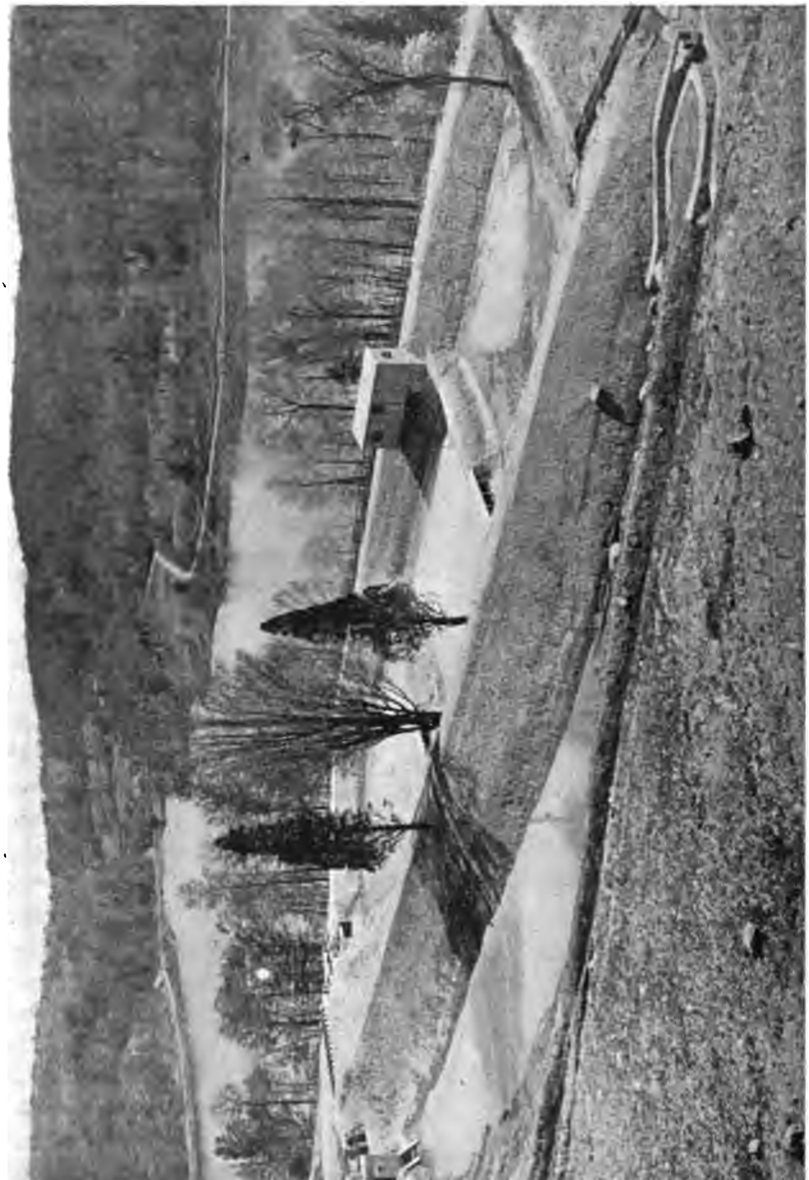


PLATE 165.—Contract 24. View of Croton Lake, Showing Filters Used to Purify Water from Camp Bradley.

This feature of construction is to provide for the interval previous to the completion of the aqueduct into the city.

Downtake Chamber. The downtake chamber of the Croton Lake siphon is so built as to provide for connections with possible future high-level aqueduct to some of the upper Croton reservoirs. Such an aqueduct would enable a portion of the Croton supply to be delivered into New York with the pressure of the Catskill water.

Central Power Plant. A central compressor plant was built about 2500 feet east of the aqueduct line, consisting of two Heine water-tube boilers, 210 H.P. each, to which later was added a marine boiler of 240 H.P. Two Ingersoll-Rand Imperial Type X air compressors, each of 1750 cubic feet capacity, operated by cross-compound condensing engines, equipped with condensers, furnished power through 6-inch and 7-inch pipe lines to the shafts. Two 35-K.W. electric generators furnished current for lighting.

Turkey Mountain Tunnel. This is a grade tunnel 1400 feet long of the ordinary section, and was excavated by the usual top-heading and bench method. An average weekly progress of 28 feet in heading and 34 feet in the bench was made. The maximum weekly progress was 54 feet of heading and 51 feet of bench. After the footing courses were concreted, the side walls and arch were placed, using the standard Blaw forms. An attempt was made to drill this tunnel close to line, but it was found upon concreting that considerable trimming was necessary.

Concreting Turkey Mountain Tunnel. The concrete was mixed near the Downtake shaft and taken in side-dumping cars to the portal and dumped through a chute to a tunnel car, which was hauled by a cable hoist up an incline to the form platform 12 feet above invert. The plates were in place up to the platform and the side walls were filled directly from the cars. Above the platform the plates were put on and the concrete shoveled in. No spading was done, the mass being compacted and the air expelled by striking the inner forms with a hammer. This method gave good results with a smooth face comparatively free from voids. It is not to be recommended as a substitute for the spading of concrete. By this method it is necessary to have the concrete homogeneous and uniform in mixture, as any separation of the materials of the concrete cannot be made good by shoveling. The side walls and arch were placed in one continuous operation, first in a section 20 feet long, and later in lengths of 60 feet, the latter taking from thirty to forty hours. To facilitate the keying of the arch in the 60-foot section the work was started from each end, and the closure made by using three T-shaped con-

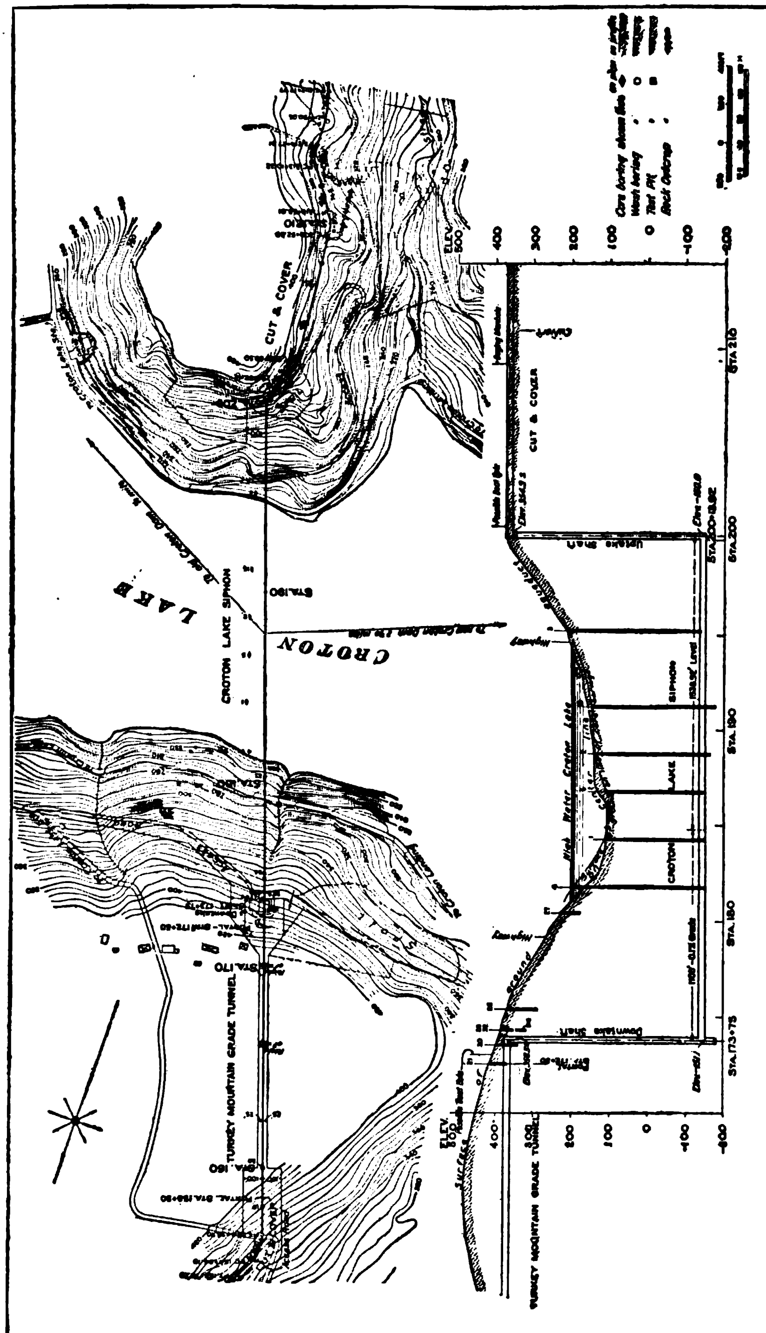


PLATE 166.—Contract 24. Croton Lake Siphon. Contour Plan and Profile of Pressure Tunnel Showing Vertical Borings, etc.

crete blocks, each 1 foot long, the center one provided with a pipe through which grout could be forced to fill the space at the closure. Later, sections as long as 90 feet were concreted in one operation. The concrete was obtained from a mixer placed in the adjoining cut-and-cover aqueduct and fed with concrete materials by cars which dumped through a hole in the arch, the mixer being discharged into the concrete cars below which were carried to the concrete platform as usual.

Construction of Croton Shafts. The two shafts of the Croton siphon were constructed by Harry & McNeil, with a plant which had previously been used on the Rondout siphon. The excavation was started with a derrick which was later superseded by head frames through which buckets were operated in the usual manner. The maximum weekly progress was 23 feet, the average 13 feet. The rock was an excellent schist containing very little water. The downtake shaft was circular with a rectangular extension to the blow off. The circular part was drilled with eight 10-foot cut holes, twelve 8-foot side holes, and fifteen 8-foot rim holes, fired in three shots. The rectangular extension was kept 10 to 20 feet higher than the main shaft and shot as a bench. The shaft was concreted, using circular Blaw forms, a 10-foot section usually being concreted each day in four or five hours, the remainder of the day being used in removing and setting up forms.

Drill Frame for Shaft. In the construction of this shaft a drill frame designed by Mr. Harry was used. This frame consists of a ring from which radiates several bars equipped with jacks at their ends. The ring with the bars was lowered into place by cables attached to a drum of a hoisting engine. The drills were then clamped to the radial bars and the three circular rows of holes drilled. It is claimed for this frame or spider that it much facilitates the drilling of a circular shaft by furnishing a firmer support for the drills than the usual tripod; also by increasing the speed with which the drills may be removed and lowered into the shaft after shooting. The drill frame may be raised with some or all of the drills attached. The ring may be made from pipe and equipped with connections so as to serve as a manifold for the drills, and thus decreasing the amount of flexible hose otherwise necessary. Drill frames somewhat similar to this have been used in England and it is claimed with a good deal of success.

Uptake Shaft. The uptake shaft, which is 505 feet deep, was constructed in a similar manner. The average weekly progress was

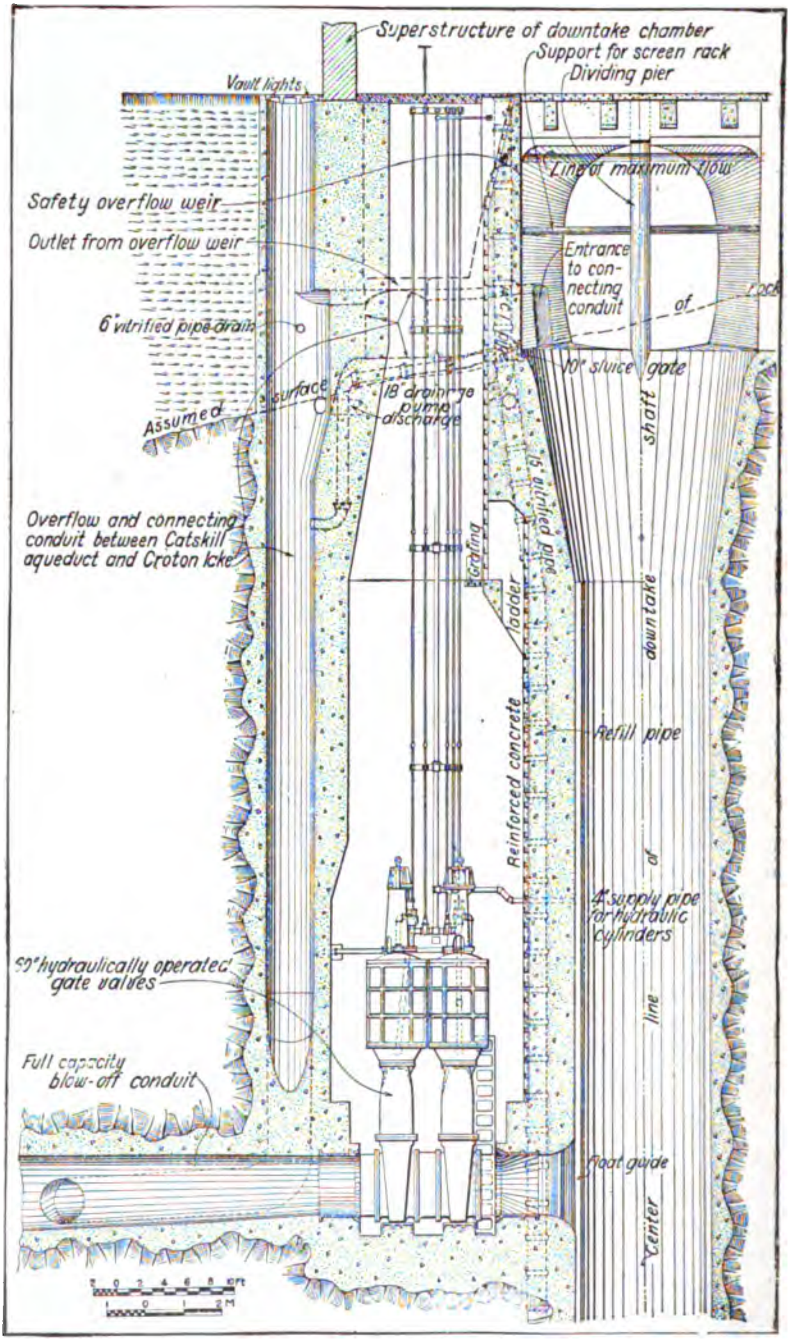


PLATE 167.—Contract 24. Croton Lake Downtake Shaft. Shows how flow into Croton Lake through conduit is controlled by gate valves. Overflow weir also discharges into conduit to lake.

16 feet and the maximum 25 feet. The maximum weekly progress in lining was 76 feet.

Shaft Equipment. Permanent tunnel equipment was installed after the shafts were sunk and concreted. High head frames were constructed so that muck cars could be dumped directly in the crushers. The shafts were equipped with Lambert air hoists and a single Lambert cage. This cage was counterweighted and raised and lowered between wooden guides constructed in a rather unusual way. Cables were suspended from the top to the bottom of the shaft and boxed in to the dimensions of the usual timber guide. The cage was equipped with the usual safety dogs which gripped the suspended guides. In this manner it was unnecessary to drill the concrete for bolts by which wooden cross-pieces are fastened, these in turn supporting the guides, as in the usual construction. It seems to the writer, however, that the usual arrangement is safer, for in case of accident to the suspended guides, a bad wreck might result. Although the distance between the uptake and downtake shaft is only 2640 feet and the one cage was probably adequate, it would appear that the extra cost of installing two cages would probably have been warranted by increased facility in operation and the time saved at critical moments.

Excavation of Croton Pressure Tunnel. The tunnel was driven with an equipment of Ingersoll-Rand drills, using a top heading. At the beginning of the work an attempt was made to carry along the bench so close to the heading that the muck from the latter would be shot over the bench, saving wheeling. This did not prove satisfactory, as the two operations of drilling heading and bench and mucking heading and bench were hampered by lack of room. This repeated the experience of other parts of the work where the same attempt was made. The tunnel was then driven nearly through and the bench later excavated. The tunnel proved to be unusually dry, the inflow with the shafts only being about 33 gallons per minute, which is less per foot than some of the adjoining grade tunnels. The heading was excavated by the following method: A drilling shift of 14 men, including 4 drillers and 4 helpers, drilled most of the holes in their shift. The next shift completed the drilling and shot the heading; the third, a mucking shift, cleared the heading, so that it was ready for the setting up of the columns and drills for the next shift. This mucking shift consisted of 1 foreman and 6 laborers, and overlapped a regular mucking shift of 1 foreman and 11 laborers. The bench was drilled by two tripod drills, operated by 3 drillers, each shift drilling and shooting a round of six holes in transverse rows $3\frac{1}{2}$ feet apart. Meanwhile mucking was going on steadily in three shifts with 1 foreman and 8 laborers. The muck from the heading was crushed at the downtake shaft for the concrete and that from the bench at the uptake shaft. The best progress made was about 250 feet of heading in one month and about 108 feet of bench per week.

Concreting Pressure Tunnel. Concreting was done in a manner very similar to that of the Wallkill tunnel. It was found feasible to concrete an invert strip 6 feet wide instead of a 5-foot strip, which was said to be of considerable assistance in preparing for the side-wall forms. Steel Blaw forms equipped with carriages the same as those used on the Wallkill siphon were used, and the method of trailing forms followed. Twenty-five feet of arch and side wall were usually concreted in a day. This tunnel is 14 feet in diameter and the lining is 13 inches effective thickness, 8 inches to the A line.

The cut-and-cover stretches were excavated by derrick and the material deposited on spoil banks. The concrete was placed against Blaw forms by a Browning crane, a 30-foot section being completed in eight hours. Later the crane was used for refill over the arch and to grade the embankments.

Blow-off Conduit. Under Contract 24 about 730 feet of the blow-off conduit into Croton Lake was constructed, 450 feet in tunnel, $6' \times 6'$, and the remainder in cut-and-cover, $6' \times 8'$. This tunnel joined the downtake shaft 80 feet below the invert level of the chamber. Two 60-inch gates (in tandem) will control the flow from the main shaft. By setting stop planks in the downtake chamber, water may be sent through a by-pass and drop manhole into the blow-off tunnel without going into the main shaft. It will then be under such a head that the very steep $6' \times 8'$ conduit below will carry the full capacity of the aqueduct at an estimated velocity at the lake of about a mile a minute. This velocity of discharge makes the design of this conduit a very interesting one, particularly so as the outlet is on an earth slope. It was decided that an open channel was preferable to a closed conduit, as it was feared that the latter would give trouble because of air being confined. The unique part of the design adopted is the spreader with which the channel terminates. This has an invert curved upward so as to throw the water out in a sheet while at same time spreading it so as to fall as far as possible from the terminal structure. Further protection is furnished by a small concrete apron and a large rock fill. The spreader will only come into full use when the lake is below the lip of the spreader at elevation 164. The maximum flow line of the lake is 202 feet. It has been computed that with a maximum possible discharge of 1000 million gallons per day the center of the descending sheet of water will fall at a distance of about 130 feet from the end of the spreader. With a discharge of 50 million gallons per day the distance will be about 25 feet. Coefficients of friction for velocities as high as those which may obtain in this channel (maximum 75 feet per second) are unknown, and the computations are subject to large errors.

CONTRACT 100

Outlet of the Croton Blow-off. The lower 150 feet of the Croton blow-off as above described was let under Contract 100 to Stobaugh & Co., for $41,500. At this time the surface of the Croton Lake was about 40 feet below flow line, making it possible to construct outlet and spreader in shallow water. This was accomplished by a three-sided cofferdam of Lackawanna steel sheathing. The piles were driven into the bottom with a steam hammer and rendered tight by dumping wood pulp outside the cofferdam. The remaining leakage was readily handled by a small pump. The spreader was then built on a good foundation of hardpan and the projecting steel piling cut off above the level of the riprap by an oxy-acetylene flame. The bulk of this work was accomplished within a few weeks in the fall of 1911. The Lake was low at the starting of the work, but rose rapidly thereafter, so that the work had to be pushed with much vigor, but was completed in time to avoid damage by flooding the cofferdam.

CONTRACT 25

Contract Prices. Contract 25 was awarded to Chas. W. Blakelee & Sons, April, 1909, for a total of $1,269,830. Some of the bid prices were as follows:

Open-cut excavation, cu.yd.	$0.50 to 1.30
Refilling, embanking, cu.yd.	0.35 to 0.45
Concrete masonry for open-cut aqueduct, cu.yd.	5.10
Rock excavation in tunnel	5.95
Timbering in tunnel, M ft. B.M.	50 to 60
Concrete masonry in tunnel, cu.yd.	5.65
Forms for lining tunnel, linear foot	3.00
Sanitary provisions, per month	225.00
Medical and surgical practitioner, per mon.	200.00

From contract quantities the linear foot cost of cut-and-cover is $67, of grade tunnel, $102.

Kind of Work. This contract lies just south of Croton Lake, and includes 2.5 miles of cut-and-cover and 0.7 mile of grade tunnel from north to south, as follows: 1050 feet of cut-and-cover aqueduct, 3000 feet of Croton grade tunnel, 3500 feet of cut-and-cover, 700 feet of Chadeayne grade tunnel, and 8700 feet of cut-and-cover. The southern end of the work was reached from the Putnam division of New York Central Railroad, to which a spur track was constructed for the contractor's use. The northern end was reached from Kitchawan by team.

Camp Sanitation. As the work lies very close to the intake to Croton aqueduct the sanitary provisions were stringent, and what is considered one of the best camps on the line of the Catskill Aqueduct was established. About forty buildings, including incinerators, were erected and supplied with electric light, running water and stoves. The entire camp was surrounded by a man-proof fence. The water supply was obtained from two driven wells and the sewage and drainage from camp led to filters. All the garbage was collected daily and all excreta incinerated. At points convenient to the work movable shelters for sanitaries were placed and tight cans provided, the contents being collected and burned daily at the incinerators. At Croton and Chadeayne tunnels chemical dosing plants sterilized the water from the tunnels and from the brook running from camp filters.

Power Plant. A central compressed-air plant was installed near the south portal of Croton tunnel and used for both grade tunnels. Steam was furnished by four fire-tube boilers of 100 H.P. each, two Ingersoll-Rand 125 H.P. compressors, each of 1075 cubic feet capacity, and equipped with condensing, circulating and feed-water pumps. Power was distributed through 3400 feet of air line. One 30 K.W.A.C. dynamo and one 22½ K.W.D.C. dynamo supplied current for lighting.

Croton Tunnel. The Croton tunnel was driven entirely from the south portal. The top heading and bench method was employed for a distance in, after which the bottom heading was tried for a few hundred feet, and finally the top heading alone was driven to the north portal. Ventilation was supplied by a blower and pipe, but later three holes driven near the north end of the tunnel from the surface by a Keystone drill supplied ample ventilation.

When the top heading method was used the usual arrangement of holes was employed, consisting of three rounds of about 24

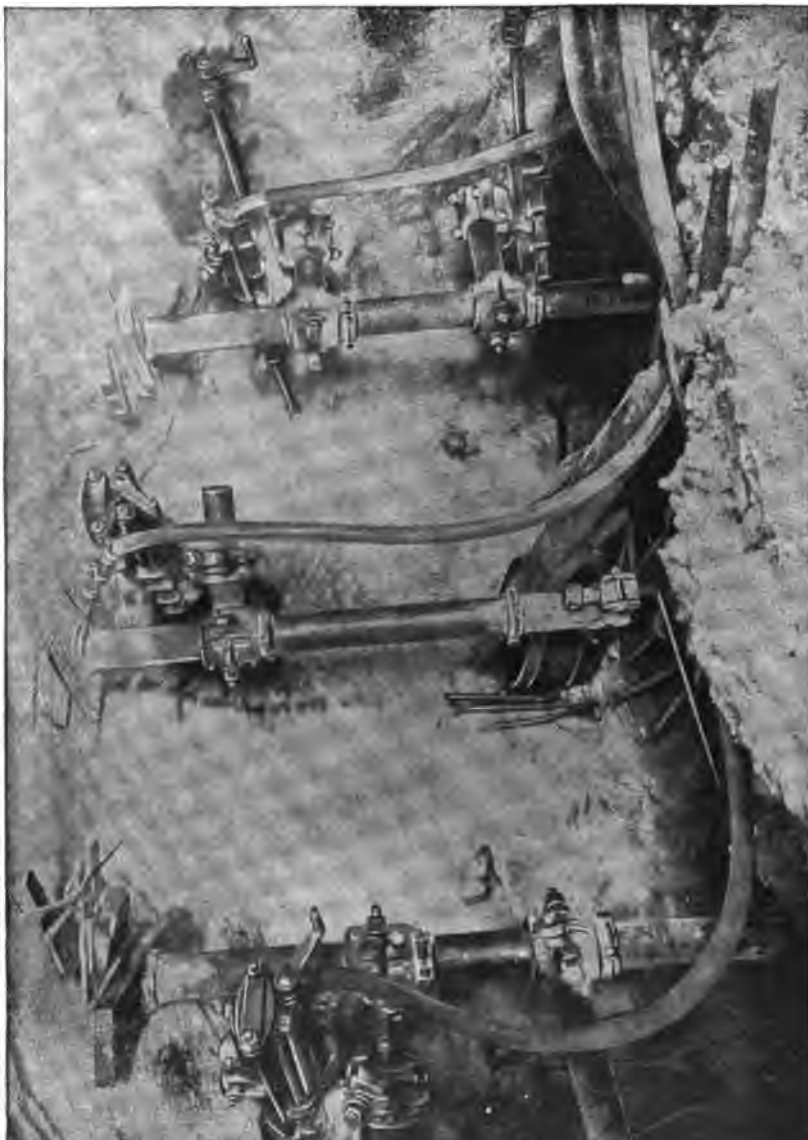


PLATE 168.—Mounting of Piston Drills on Columns in Tunnel Heading.

holes drilled from columns by Ingersoll-Rand piston drills F24 and E29. The holes were shot in three rounds, delayed-action electric exploders being used occasionally in the two bottom corner holes when the rock was hard-breaking.

Excavation was accomplished in two shifts of 4 drillers, helpers, etc., and three shifts of 8 muckers. This gave a four-hour interval between the drilling shifts for mucking out the heading and setting up the drill columns, so that the drillers could get to work without

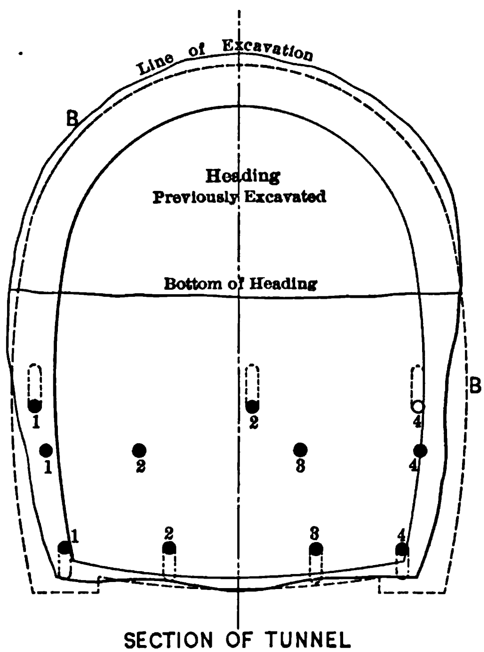


PLATE 169.—Grade Tunnel Cross-section, Showing Method of Placing Horizontal Holes for Excavating "Bench."

delay. The muck was hauled by horses to be later loaded on stone cars and carried to the crusher during the day shift. The maximum weekly progress was 73 feet.

System of Horizontal Holes for Bench. A peculiar system was used in the Croton tunnel for the excavation of the 9-foot bench. Six holes about 9 feet long were drilled horizontally from tripods, the holes on the perimeter of the tunnel pointing outward slightly so as to terminate near the C line. Two rows of holes were employed loaded with 40 to 60 per cent forcite and shot with fuses or delayed-action electric exploders, as follows: First, the upper center holes, then two upper side holes, then the lower center hole and then two lower side holes. All the fuses were touched off at once, or a current sent simultaneously through all the exploders, the order of shooting being governed by length of fuse or setting of exploders.

Horizontal vs. Vertical Holes for Bench. One drilling shift of 2 drillers, helpers, etc., and two mucking shifts of 8 muckers were employed, in excavation of the bench, giving an average advance of 65 feet per week, a maximum progress of 79 feet being made. This system has the advantage of excavating a tunnel with the lower half driven closer to the line than that obtained by the usual method of vertical holes. Because of the curved sides of the tunnel it is usual to find the sides tight midway thereof, necessitating some trimming. It seems, however, that the vertical-hole method has the great advantage of enabling the rounds to be drilled as far ahead of the shattered bench as desired, so that the shooting may take place at any time. A considerable stretch of bench can be shot up in advance, although blasting against the muck requires the use of more powder with some danger of the bottom shooting high, necessitating additional holes later on. With the method employed in the Croton tunnel the holes cannot be placed until the face of the bench is cleared of the muck, and it is rather awkward to drill horizontal holes from tripods. The methods employed in the Croton tunnel were very good, but in the writer's opinion more economical results are secured by carrying the bench along with the heading, using vertical holes for the latter and employing the same schedule of drilling shifts and mucking shifts, but increasing the number of men sufficiently to carry on the bench.

Cut-and-cover Excavation. The cut-and-cover excavations were made mainly with steam shovels, of which there were employed two 60-ton Marion, one with 35-foot boom, one 20-ton Marion, and one Vulcan shovel. The material excavated by the shovels was loaded directly into cars hauled by dinkies to spoil banks or to make refill over the completed concrete arch. The final excavation not possible by the steam shovel was shoveled by hand into scale boxes and removed by derricks and locomotive cranes to the cars. Large rock cuts were drilled and blasted, the shattered material being moved by pick, shovel and derricks and deposited on banks or taken to crushers.

Crushing Plants. The crushing plant over the Chadeayne tunnel received the tunnel muck directly from the bins at the portal and consisted of a No. [illegible] Kennedy gyratory crusher operated by a [illegible] H.P. engine. A bucket conveyor discharging into bins [illegible] × [illegible] × [illegible] was used.

A second crushing plant was built on leased land near the south end of the contract and consisted of jaw crusher with screens, bins, etc. The crusher supplied material for two Chicago cubical mixers at the portal. Ground storage was resorted to so as to have an ample supply of crushed stone on hand at all times.

Concreting Cut-and-cover Aqueduct. Concrete was placed in the cut-and-cover aqueduct by the usual methods, using bottom-dump buckets hauled in dump cars by dinkies to the site of the work and dumped into place between Blaw steel forms by locomotive cranes or derricks. The invert of the aqueduct was reinforced when on clay bottom and at points where the materials changed suddenly from rock to earth. At some places it was placed 24 inches thick, and at others it was reinforced by steel rods. The concrete was obtained from two mixing plants. Maximum invert built in one week was 440 feet, and the maximum arch was 435 feet; 30- to 45-foot sections were concreted in one day.

Plant and Equipment. This contract was very well started. A railroad track was gradually extended from the Putnam Railroad at Millwood to the north end of the work, the railroad equipment consisting of 6700 feet of 36-inch-gauge track, 8 dinky locomotives, 1 standard-gauge locomotive, 58 dump cars, etc. Other plant consisted of 18 steel tunnel cars, 2 Keystone well drills, 1 churn drill, 24 rock drills, 1 stiff-legged derrick, 2 Brown hoists, 18 guy derricks, and 14 hoisting engines with boilers, 180 feet of Blaw cut-and-cover forms, and 60 feet of Blaw steel tunnel forms, etc.

Refill over Aqueduct. Refill for the aqueduct was obtained from the excavation direct, from the spoil alongside of excavation, or from a spoil bank where a 60-ton Marion shovel loaded cars which were hauled and dumped over the arch. Some material was replaced over the arch by the Brown hoist.

Chadeayne Tunnel. Chadeayne tunnel was excavated from one end, drilling the heading through first and then excavating the bench. The heading averaged 44 feet per week, the bench 47 feet. Muck was loaded into the scale boxes on cars, pulled to the portal and hoisted upon the cars to the crusher on the spoil bank. The tunnel was concreted in the usual manner with Blaw forms equipped with carriage and inclines. The concrete placed in the arch averaged 60 feet per week, using one eight-hour shift per day. The

PLATE 170.—Central Concrete Mixing Plant of Large Capacity. Sand and stone raised to bins by derrick with "grab" bucket. Concrete mixed in tilting mixer which discharged into bottom-dumping buckets hauled to site of work on cars.

and consisted of a No. 5 Kennedy gyratory crusher operated by a 50 H.P. engine. A bucket conveyor discharging into bins 100′×18′ ×15′ was used.

A second crushing plant was built on leased land near the south end of the contract and consisted of jaw crusher with screens, bins, etc. The crusher supplied material for two Chicago cubical mixers at the portal. Ground storage was resorted to so as to have an ample supply of crushed stone on hand at all times.

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Chadeayne Tunnel. Chadeayne tunnel was excavated from one end, drilling the heading through first and then excavating the bench. The heading averaged 44 feet per week, the bench 47 feet. Muck was loaded into the scale boxes on cars, pulled to the portal and hoisted upon the cars to the crusher on the spoil bank. The tunnel was concreted in the usual manner with Blaw forms equipped with carriage and inclines. The concrete placed in the arch averaged 60 feet per week, using one eight-hour shift per day. The

PLATE 170.—Central Concrete Mixing Plant of Large Capacity. Sand and stone raised to bins by derrick with "grab" bucket. Concrete mixed in tilting mixer which discharged into bottom-dumping buckets hauled to site of work on cars.

same method was used in the Croton tunnel, but the progress was 80 to 160 feet per week, using two eight-hour shifts.

In general, very good progress was made on Contract 25, the entire work being nearly completed within forty-four months, nearly eight months ahead of contract time.

CHAPTER XV

CONTRACT 55

GRADE TUNNELS, CUT-AND-COVER AND PRESSURE AQUEDUCTS

Contract Prices. The contract was let October, 1909, to Rinehart & Dennis, for a total of $4,545,000. Some of the items are given below:

Open-cut excavation, per cubic yard	$0.80 to $1.00
Rock excavation, per cubic yard (open cut)	1.00
Refill, per cubic yard	0.10 to 0.25
Mass concrete, per cubic yard	5.00 to 5.25
Reinforced concrete for by-pass aqueduct, per cubic yard	5.75
" " for gate chamber, per cubic yard	8.00
Rock excavation in tunnel, per cubic yard	5.00
" " Lakehurst tunnel, per cubic yard	5.50
Forms for masonry lining in tunnel, per foot	2.50
Concrete in tunnel, per cubic yard	5.50
Steel for reinforcing concrete, per pound	0.04
Portland cement, per barrel	1.60

Using contract quantities the linear foot cost of cut-and-cover is $77.84, grade tunnel $94.02, by-pass aqueduct $46.91, Lakehurst tunnel $62.45, and effluent aqueduct $102.98.

Work Included. This contract extends from near Millwood on the Putnam division of the New York Central Railroad to a point near Kensico Cemetery station on the Harlem Railroad, crossing that railroad near Pleasantville. It is one of the longest of the cut-and-cover and grade-tunnel contracts, the total contract price being the greatest. It contains gate houses and effluent chambers from the Kensico reservoir, including an aeration basin. To bring the aqueduct to Kensico it was necessary to take it away from a favorable north-and-south location, and lead it across country through several tunnels and even somewhat below hydraulic grade, making necessary a circular pressure aqueduct nearly 3 miles long. It contains eight grade tunnels, the last three under slight pressure, aggregating in length 3.7 miles, the tunnels from north to south being known as Millwood, 4750 feet long; Sarles, 5230 feet long; Harlem

R. R., 1100 feet; Pleasantville, 700 feet; Reynolds Hill, 3650 feet, Lakehurst, 1650 feet; Dike, 1166 feet; and Kensico, 1515 feet; and about 3 miles of cut-and-cover aqueduct. The total construction aggregates 9.6 miles of aqueduct, including more types of special structures than any other contract.

Influent Weir and Venturi Meters. At the point where the cut-and-cover approaches the future Kensico reservoir the aqueduct is constructed so as to feed the reservoir through a section about 200 feet long built so as to open toward the reservoir, the structure being known as the Kensico Influent Weir. One side of the aqueduct is built with the standard section and the other as a heavy weir, with a gap of about 4 feet through which the water is to flow. The crown of the arch is supported by piers 18 feet apart. This construction is shown on Plate 174. Near this point there is also an influent chamber equipped with gates and stop planks. From the weir an inlet channel is excavated to the reservoir. There are two Venturi meters similar to that at Ashokan to be constructed under this contract to measure the water flowing in and out of this Kensico reservoir. At the outlet of the reservoir there are two effluent gate chambers, an aeration basin and a screen chamber.

Putnam Siphon. Crossing the Putnam Railroad is the Putnam siphon, which is reinforced concrete circular section, instead of the steel pipe usually used. This structure is about 600 feet long and will be under a maximum head of about 50 feet.

Circular Tunnels. The contract is also peculiar in containing grade tunnels of circular section under slight pressure, 11 feet to 17 feet in diameter.

Main Power Plant. A standard-gauge siding was laid from the Harlem Railroad at Kensico Cemetery, where land was leased for a yard, cement shed, power plant, etc. From this point a narrow-gauge railroad extended as far as Pleasantville in the Croton Division, which contains the upper 6 miles of this contract. The power plant contains three 125-H.P. boilers and two Ingersoll-Rand compressors of 1100 cubic feet free-air capacity. Eight-inch to 3-inch compressed-air lines laid from this plant furnish power to three tunnels of the Kensico Division, for drills on the inlet channel and quarry and excavation for the by-pass aqueduct, and Reynolds Hill tunnels. The pipe lines total 4.5 miles. At the power plant was also operated a 30-K.W. A.C. current generator which provided light for the tunnels from Reynolds Hill south and for Camp Columbus. The current was transmitted over 13,000 feet of pole lines and connections.

Plate 171.—Venturi Meter in Construction. Bronze Throat Casting being Set. Portion under Pressure Reinforced. This meter will record the full flow of the cut-and-cover aqueduct. There are three of this type above the city line and one in City Aqueduct Tunnel.

Second Compressor Plant. Another compressor plant was built on a siding to the Putnam Division near Millwood. This plant consisted of three 125-H.P. locomotive boilers and one Rand straight-line air compressor of 1300 cubic feet capacity. About 3400 feet of 4-inch pipe and 1800 feet of 3-inch pipe conveyed air for the north heading of the Millwood tunnel and the cut-and-cover aqueduct north of the portal. Light was furnished by 160-K.W., 1100-volt Westinghouse generator.

Third Compressor Plant. A third power plant was located at the Harlem Railroad at the aqueduct crossing between Sarles and Harlem Railroad tunnels. It contains three 150-H.P. fire-tube boilers, and two Ingersoll-Rand compound non-condensing compressors, each rated at 1200 cubic feet of air per minute. One Westinghouse A.C. 50 K.W. generator furnished light for the tunnels and for two camps.

Quarry and Sand Pit. At the north end of the by-pass aqueduct a quarry was established at the base of a steep cliff of gneiss rock, and a crushing plant fed by gravity from the quarry floor. A No. 6 Kennedy crusher was charged by mule-drawn cars from the quarry. The crushed material was run by a conveyor into a rotary screen, where it was sorted into bins for 2-inch and $\frac{3}{4}$-inch stone and crusher dust, combined capacity 1100 cubic yards. The stone of this quarry was used as far north as Pleasantville, all parts of this work being reached by narrow-gauge tracks. The sand-pit near the crusher was operated by a derrick equipped with a clam-shell bucket; sand was also elevated into bins by a bucket elevator and some crushing of stones done at this point. Later the derrick and crusher were removed and the sand excavated by scrapers.

Millwood Tunnel—Bad Ground at North Portal. This tunnel is 4750 feet long and was excavated from two portals. The excavation at both portals was started in June, 1910, and the tunnel was driven through with top heading, the bench being left until after the headings met. The excavation of the north heading was in hard rock until at a point 1350 feet from portal the rock became noticeably soft and blocky, and at the same time very wet. Some temporary timbering was placed, no drilling being required. An attempt was made to carry the heading forward with light timbering. After going about 40 feet a slide occurred, crushing the timbering and filling the heading. A small center drift was then driven and timbered and then side drifts were driven in which were placed wall plates. The top was then removed and a complete arch timbering placed, followed by the excavation of the core. After placing about 80 feet of timbering in this manner good rock was again encountered and excavation proceeded untimbered as before. Several months later a hole was discovered on the surface over the point where the cave-in occurred, where there is 130 feet of ground over the tunnel. To prevent further cave and to strengthen the tunnel at this point, cut-off walls were built at each end of the timbered section to contain the grout placed above the timbers. In a stretch of about 110 feet 148 yards of liquid grout were forced in by air pressure, using a Caniff grouting machine.

Method of Excavation at North Portal. For the excavation of the north heading of Millwood tunnel Ingersoll-Rand F 94 3⅝-inch piston drills were used, mounted on vertical columns. At first these drills were mounted on two columns, using 10-foot steel for cut, and 8-foot steel for side rounds, giving an average pull of 6.7 feet. Later four drills were mounted on two columns, using 12-foot steel for cut holes and 10-foot for other holes, giving an average pull of 7.6 feet. The 12-foot holes were started 2½ inches in diameter, reducing every 2 feet to 1¼ inches at bottom. The usual V-shaped cut was drilled with parallel side round. The trimming holes were started on C line, pointed to reach B line at the butts. The cut generally required to be shot twice. Electric fuses and 60 per cent forcite were used, about 6 pounds per yard.

Schedule of Shifts. The following schedule of work was followed:

Drilling shifts:
- 4.00 P.M. to 12 P.M.
- 12 P.M. to 8 A.M. (Shot at end of 2d shift.)

Mucking shift:
- 9 A.M. to 5.30 P.M. (½ hour for lunch.)
- 5.30 P.M. to 2 A.M. (½ hour for lunch.)

Drilling shift:	4 drillers, 4 helpers, 1 nipper, 1 blacksmith, 1 helper.
Mucking shift:	4 muckers, 1 dump man, 1 driver, 1 mule.

It is apparent that an attempt was made here to make a long advance per round—7.6 feet.

Method Used in Millwood and Sarles Tunnels. In the south heading of the Millwood tunnel and the adjoining Sarles tunnel it was aimed to make only a short advance—4.25 feet—at the lowest possible labor cost as follows:

Two Ingersoll-Rand drills (3⅝ inches) were mounted in the heading, each on a column, and all holes were drilled to a depth of 6 feet with the usual arrangement of V-cut, side, round and trimming holes. All holes were loaded before the first shot with 60 per cent forcite and shot in three rounds with electric exploders. About 6.3 pounds of powder were used per yard.

Schedule of Shifts. The following arrangement of shifts was used:

Drilling shifts:
- 8 A.M. to 5 P.M. (1 hour for lunch.)
- 9 P.M. until 5 A.M. (1 hour for lunch.)

Each shift drilled a round of 6-foot holes.

Mucking shifts:
- 7 A.M. until 4 P.M. (1 hour for lunch.)
- 7 P.M. until 4 A.M. (1 hour for lunch.)

Heading muckers:
- 5 A.M. to 9 A.M.
- 5 P.M. to 9 P.M.

} 2 shifts of 4 hours each.

Typical force:
- Drilling shift, 2 drillers, 2 helpers, 1 nipper, 1 blacksmith, 1 helper.
- Mucking shift, 4 muckers, 1 dump man, 1 driver, 1 mule.
- Heading muckers, 2 muckers, working ½ day on each shift.

In general the routine was for the drillers to drill and shoot the heading (about 7 feet high) in each shift; then followed a three-hour interval in which the heading was mucked back sufficiently by two muckers to allow the drills to be set up by the next shift, and to allow the heading to clear of smoke before the main mucking shift came on, two hours after shooting. In this manner two advances of about 4.25 feet per day were made of about 4 yards per foot of advance.

Advantage of Methods Used in Millwood Tunnel. The arrangement of shifts as used in Millwood South is very advantageous for eight-hour shifts. With ten-hour shifts (not here legal) there is a natural interval between which the tunnel can be cleared of smoke, etc. Where three shifts are worked per day a great deal of time is necessarily lost while blasting is going on and while the tunnel air is too thick for work. An interval of a few hours between drilling and mucking shifts gives an opportunity to clear the tunnel of smoke, and by using a few men the heading can be sufficiently cleared to allow the setting up of drills before the drillers report. Some superintendents claim that it is economical to train laborers to set the drills so that everything will be in readiness when the drill runners report. In Millwood South it was preferred to make one short advances for each shift rather than one long advance per day, as in the north tunnel. The short advance is the right principle, as 9.5 feet was made with an average force of 31 men in the south tunnel against 7.6 feet per day in the north tunnel with an average daily force of 41 men. Both headings were in hard gneiss, each encountering about 35 gallons of water per minute. An average weekly progress of 35 feet was made in the north heading and 47 feet in the south heading, the maximum weekly progress being 61 feet.

Bench Excavation by Horizontal Holes. The headings were driven shallow, leaving a bench of about 12 feet to be excavated. An attempt was made to take this out, using 8-foot vertical holes to take down the upper portion (6 feet) and 10-foot lifting holes to remove the lower 6 feet. This was soon abandoned in favor of the method of excavating bench by the use of two rows of horizontal holes as used in the Croton tunnel. The average weekly progress on the bench as made by this method was 44 feet, maximum 66 feet.

Comparison of Methods of Millwood and Bonticou Tunnels. It is not apparent that the care taken in the Millwood tunnel to carry on the excavation with the minimum force effected any saving in the yardage cost over the methods employed, for instance, in the Bonticou grade tunnel. By carrying a larger force working according to the admirable system developed in the heading Millwood South, it would seem that with two full drilling shifts working four drills at a time, two advances of say 5.5 feet each (total 11 feet) could have been made, using two heavier mucking shifts. It would also appear that a deeper heading (about 9 feet) could have been taken out with advantage, thus allowing the bench to be taken out with vertical holes in one lift. Moreover, by the use of two tripod drills for the bench work with additional muckers for the bench, a complete tunnel could have been excavated and trimmed without delaying the heading progress. The monthly progress in the heading alone at Millwood averaged about 204 feet, and maximum 240 feet, whereas in the Bonticou tunnel north over 300 feet of complete tunnel was averaged, maximum month, 425 feet. In the south tunnel of Bonticou the average progress was about 285 feet per month. It is to be noted, however, that Bonticou tunnel was driven in shale while Millwood was in gneiss.

Sarles Tunnel Progress. The Sarles tunnel, one of the longest grade tunnels in the Southern Aqueduct Department (5230 feet), is separated by about one-half mile of cut-and-cover south of Millwood tunnel, and was constructed by the methods described under Millwood tunnel. The north heading was begun July, 1910, and driven 1870 feet before the bench excavation was started. From the south portal the heading was driven 3360 feet to the meeting with the north heading and then the bench excavation was started.

Harlem Railroad Tunnel Timbering at Portal. The Harlem Railroad tunnel (1100 feet long) is separated from the Sarles tunnel on the north by a short steel-pipe siphon built under the Harlem Railroad under Contract 68. The heading was driven through to the south end from the north portal, after which the bench was excavated. The portal cut was found to be of a treacherous nature, collapsing after a heavy rain in April, 1910, and filling the cut, notwithstanding a crib work of timber. The cut was re-excavated and protected by permanent timbering for a stretch of 88 feet, such as used in grade tunnels. The five-piece arch bents were covered with 2-inch planking and filled over with 3 feet of earth. The rock in portions of this tunnel and at the north portal was found to be a thoroughly decomposed schist. This material has the appearance of rock, showing the marks and banding of rock, but it could be taken out with the fingers and kneaded into balls like putty.

Three Methods of Timbering Harlem Railroad Tunnel. There were three methods of timbering used on the tunnel. First, The heading was completely excavated and wall plates placed some distance back at the sides, supporting five-piece arch bents, covered with lagging and dry packed to the roof. The bench was taken out in two lifts, care being taken not to disturb the wall plates, which were temporarily supported by short posts when the upper lift was removed. All posting was ultimately carried to grade.

Second. Side drifts 7′×7′ were driven about 15 feet ahead and lightly supported by 2″×8″ sheeting laid box fashion. Wall plates were placed inside of the drift with some side pieces of arch rib. Then the core between was removed and the timber arch completed, lagged and dry packed, partly on $2\frac{1}{2}$-foot centers and partly on 5-foot centers. As the bench was removed 10″×10″ posts were erected, supporting the wall plates and covered with 2-inch lagging when necessary.

Third. A center top drift, 7.5′×10′ wide, was excavated and roughly arched. Then the sides were trimmed to full width and the top taken down, so as to place the five-piece timber arch, lagged and dry packed as usual. Wall plates were later used supported by posts which were lagged to protect sides, where necessary.

Concreting of Harlem Railroad Tunnel. For concreting the tunnel a plant was constructed over the north portal cut, which was timbered as described. A bridge was constructed transverse to the cut at ground level so that wagons could be driven on it, dumping sand and stone directly to bins below. Below these bins in turn a Ransome mixer was placed, so as to be fed from these bins with

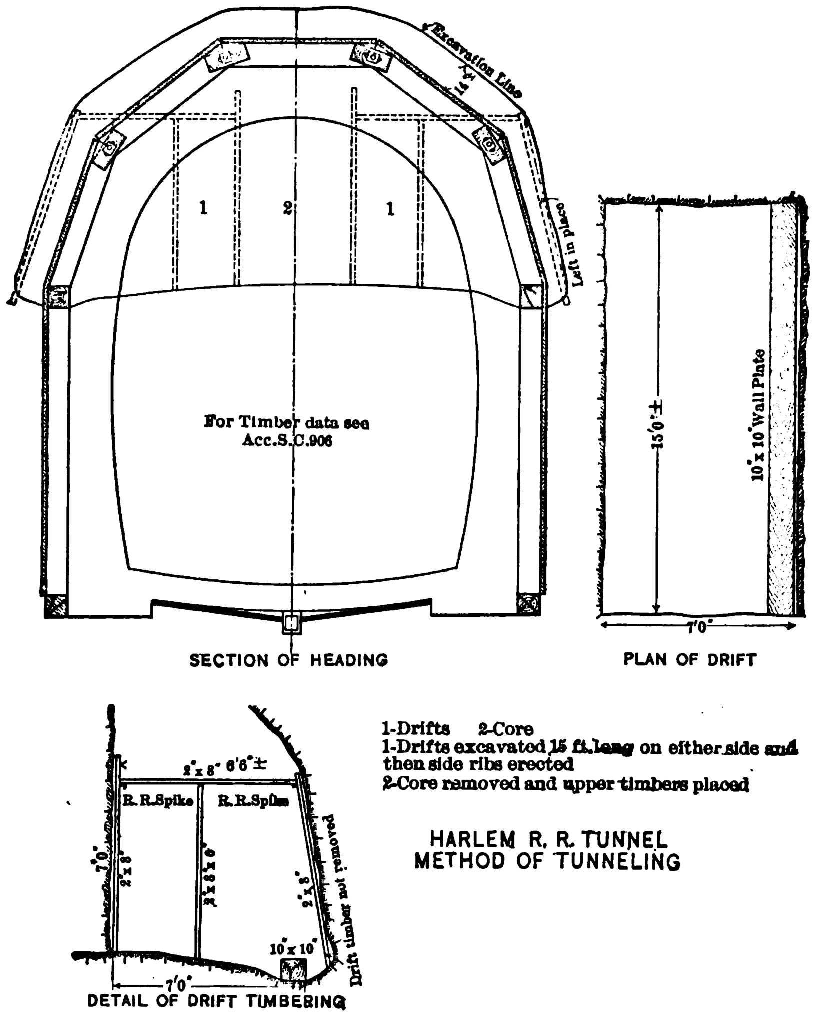


Plate 172.—Harlem R. R. Tunnel. Method of Timbering in Heavy Ground, Using Wall Plate Drifts.

sand and stone and with cement through a covered chute from a cement house on the surface. The mixer discharged directly into concrete cars running below the timber arch on a trestle about 10 feet high laid on the floor of tunnel. The trestle is a light portable construction made of 4″×6″ posts and cap cross braced with 2″×10″ planking and spaced 8 feet center to center. On the caps is laid a platform 6 feet wide, built of 2″×12″ planks, upon which the rails are spiked to a 2-foot gauge. This trestle, called a high line, connected three 40-foot sets of Blaw grade tunnel forms, eliminating the necessity for the usual inclines or elevators used to raise concrete cars from invert level. Of course, as the forms are moved it is necessary to take down and erect portions of the trestle adjacent to the forms. But it is claimed that this is a small item and that the lumber cost per yard does not exceed 12 cents. The concrete cars were at first pushed by hand from mixer to form, but later a gasolene " mule " was used. A progress of 120 feet per week was made working only one eight-hour shift.

Relative Merits of Trestle and Incline for Concreting. It is probable that the work of erecting and taking down inclines is overrated. When properly built and arranged to be carried on cars which also serve as supports for the incline, the labor upon them is not any more than taking down and erecting 80 feet of trestle, and they contain much less lumber per foot of concrete tunnel. Working one full shift of concrete men and form movers and a small keying-up shift at the Peak, Bonticou and Bull Hill grade tunnels, no trouble was experienced in concreting one 35 to 45-foot form per day. In Peak tunnel 280 feet or twice that at Harlem tunnel was averaged per week with a somewhat larger force as explained. Nevertheless, the employed method at the Harlem tunnel was very good for the purpose, the tunnel being less than one-third the length of the others mentioned. The contractor did not try to push the work of concreting the Harlem tunnel, as it was short and the work beyond not completed, but at the Millwood tunnel, using the same method, 200 to 240 feet of tunnel was lined per week.

Pleasantville Tunnel. Pleasantville tunnel is only 700 feet long. It is in crystalline limestone and was driven by the same methods and care employed in the Millwood South and Sarles tunnels.

Reynolds Hill Tunnel. Reynolds Hill tunnel (3650 feet long) pierces the divide between the Sawmill River and the Bronx, the south portal being about one-half mile from the influent weir to Kensico reservoir. It is separated by about 1½ miles of cut-and-cover from the Pleasantville tunnel on the north.

Reynolds Hill is of Manhattan schist, extends about 100 feet above the tunnel and has a rather gentle slope at the north portal, where the cover over the tunnel is less than 50 feet for about 600 feet. Several streams cross the tunnel line. At the portals there are small valleys followed also by the aqueduct center line.

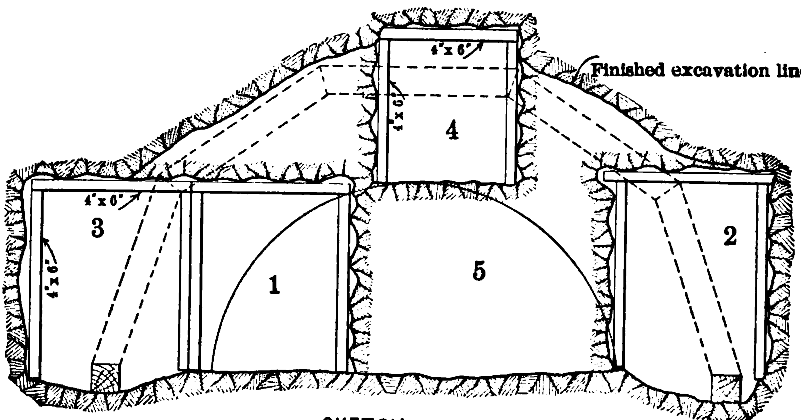
Features of Tunnel. This tunnel is notable for the bad ground encountered and the trouble and delays which ensued, although the poor ground was closely timbered and careful work and methods employed. For this reason a detailed account of south portal work is here given, and the tunnel stationing employed. Station of north portal was 652+50, that of south portal was 689+00.

Bad Ground at South Portal. The south heading was turned October 13, 1910, and the excavation proceeded by center drift 7′×12′, which was widened out for five-piece arch timbering which had been placed for 30 feet, when the bank caved at the portal and collapsed the timbering. The arch timbering was then placed block to block from 689+00 to 688+72 and packing had been placed over this timbering to 688+86 when on November 2 a second slide occurred, crushing the timbering between 688+86 and 688+72, which had not yet been packed. This was replaced and drilling resumed November 19, 1910. On December 16 the timbering was within 8 feet of face of heading at 687+30; the last two sets were not yet dry packed, but no considerable excavation had been made outside of the timbers. The heading at 687+40 then started to cave and continued until the night of December 20, when the surface of the ground was reached at a point 50 feet above roof. Special timbering was placed between 687+38 and 689+00 by the method shown on Plate 173.

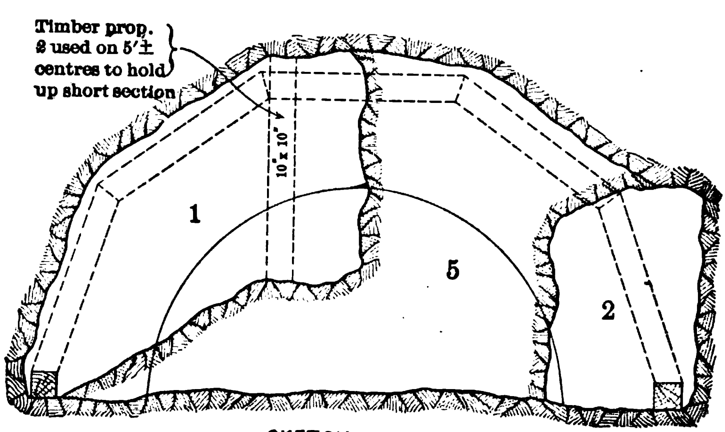
Securing Tunnel after Cave-in. After the cave-in an effort was made to hold the sides with vertical sheeting, but constant caving of the sheeting compelled the contractor to abandon this plan and a horizontal platform of heavy timbers was constructed above the tunnel timbering to afford protection for the men. Bulkheads were built at 687+38 and 687+29, and concrete placed about timbering within these limits. In the meantime, mucking out of the tunnel and placing of the timber continued.

On January 23, 1911, drilling was resumed in the heading, at which time another slide caused further delay, developing, as it was mucked, into such proportions that it took until February 6 to remove the accumulated muck and complete timbering to Station 687+22. A side drift was then started on the right side of the tunnel and carried to 686+82, a cross drift then carried to the left side of the tunnel and a drift carried to the south, permitting the setting of wall plates. The core was then removed, being excavated in advance of timbering only enough to permit placing of one ring at a time, the sets being placed back to back. The left side drift was advanced to permit the setting of

Note—These sections are shown looking North, toward heading



SKETCH "A"
Timbered Drifts



SKETCH "B"
Untimbered Drifts

PLATE 173.—Reynolds Hill Tunnel. Method of Timbering Heavy Ground between Stations 687+22 and 687+06.

other wall plates. By March 10, the slide had been caught up to Station 686+82 and work on the heading resumed, using side drift to 684+92. It thus took between December 20 and March 10 to secure the stretch of only 60 feet of bad ground. Between

687+50 to 687+39 the timbering was so badly distorted by the slip that the dry packing outside was grouted before proceeding with the bench excavation. The full heading was excavated between 684+90 and 677+20, work being then discontinued on heading, and the bench excavation resumed. The Reynolds Hill tunnel will probably be the last on the Southern Aqueduct Department to hole through.

Lakehurst Tunnel. The Lakehurst tunnel, 1650 feet long, was excavated during 1910, the headings being driven nearly through before the bench work was started. The bench was excavated by drilling horizontal holes. Permanent timbering was placed for about 1000 feet in different stretches.

The Lakehurst grade tunnel is of special shape, circular, 11 feet finished diameter, and has a horseshoe-shaped waterway 11 feet high and 12.5 feet wide.

Kensico Tunnel. The Kensico tunnel, 1515 feet long, was driven through with top heading between February 14 and July 16, 1910. The top heading was small, not over 6 feet high. A special steam shovel was used in mucking the north heading, and a conveyor was installed for transporting the excavated material to cars at the rear of the shovel, but the excavator did not work and, together with the shovel, was taken out of the tunnel. There is no instance known to the writer of the profitable use of a steam shovel or mucking machine in any of the tunnels of the Catskill Aqueduct. The north bench was removed in two lifts.

Dike Tunnel. The Dike tunnel connects the upper and lower effluent chambers of Kensico reservoir. It was excavated by a middle heading 7 feet high to full width of tunnel, leaving a 5-foot bench. The roof was removed by from four to six holes, 13 feet long, for 12-foot advances. The bench was removed by four vertical holes for 5-foot advances.

Cut-and-Cover Methods. The cut-and-cover on Contract 55 aggregates 3 miles in about six stretches between the numerous tunnels. Consequently no very good opportunity offered itself to develop methods for this class of work. In general, standard methods of excavation were used, steam shovels being employed wherever practicable, sometimes the material being cast to one side of the trench and sometimes loaded on dinky trains for spoil banks, or refill over arch. A long-boom Marion shovel was employed in a rock cut, working to near subgrade, the rock from the final trimming being loaded by hand into scale boxes and raised and dumped to one side by A-frame derrick. Concreting was done

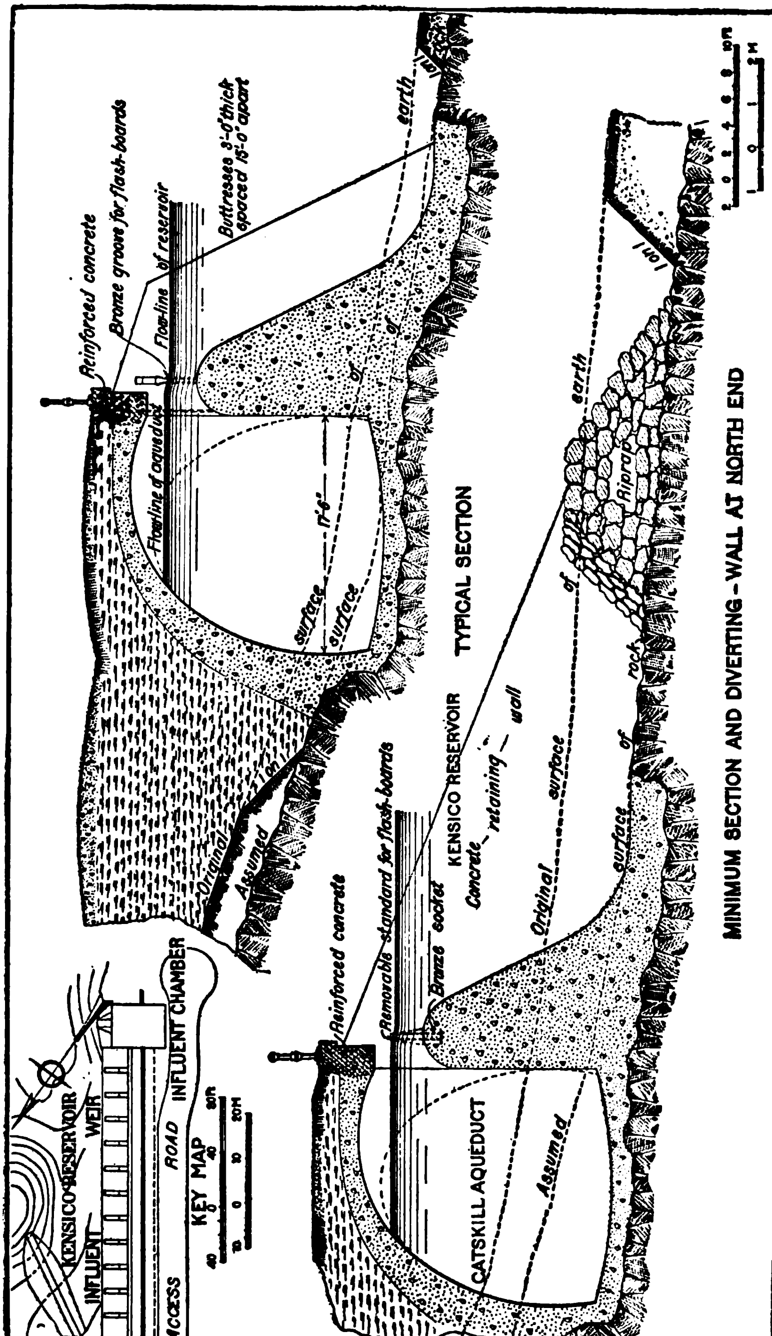


PLATE 174.—Contract 55. Kensico Influent Weir, for Feeding Kensico Reservoir from Catskill Aqueduct.

in the usual manner, Ransome cut-and-cover forms, filled by buckets of concrete hauled on flat cars and deposited by Brown hoist or derrick, being used.

Location and Design of By-pass Aqueduct. The by-pass aqueduct which connects the influent weir with the upper effluent gate chamber of Kensico reservoir is of the type known as pressure aqueduct; that is, it is an aqueduct built in open cut so as to resist a moderate internal pressure. This stretch, to secure favorable alignment, is located entirely below hydraulic gradient. There is a head available for delivering water between the influent weir and the upper effluent chamber of about 32 feet. This may be reduced to 22 feet when the Eastview filters are in operation, at which time the maximum head will be about 19½ feet on center. The maximum possible head might be 42 feet. The by-pass aqueduct is located within the flow line of the reservoir, so that when the reservoir is full it will be completely submerged. The weight of the masonry is such that it cannot float even when empty. The waterway is circular and 11 feet in diameter. The outside is horseshoe-shaped, about 1 foot thick at the crown. The sections are shown on Plate 175. It is reinforced with steel so that under usual working conditions the steel will be stressed less than 2000 pounds to the square inch.

The by-pass is designed to be covered by an embankment of earth and rock, but the slopes being submerged are made much flatter than those for the standard aqueduct. Culverts will take care of the surface flow before the completion of the reservoir and prevent the formation of pools, in case the reservoir should be subsequently drawn down.

Construction of By-pass Aqueduct. The by-pass aqueduct was excavated with a 65-ton Marion steam shovel to within 1 foot of subgrade, and the material excavated used for foundations and embankments, in spoil banks, or as refill. The bottom of the trench was shaped to the invert by hand just before the concrete was placed. It was constructed with circular Ransome telescopic steel forms in sections 7.5 feet long, the forms being supported on concrete blocks built to line and grade of invert. For use on curves steel fillers were bolted to the forms. The outside forms were also steel and horseshoe shape, resting on rock bottom or on its concrete cradle, and equipped with doors so placed that all parts of the inside forms could be reached with straight rammers. The difficulties of securing a perfect cast of a full circular section in one operation are well illustrated by the

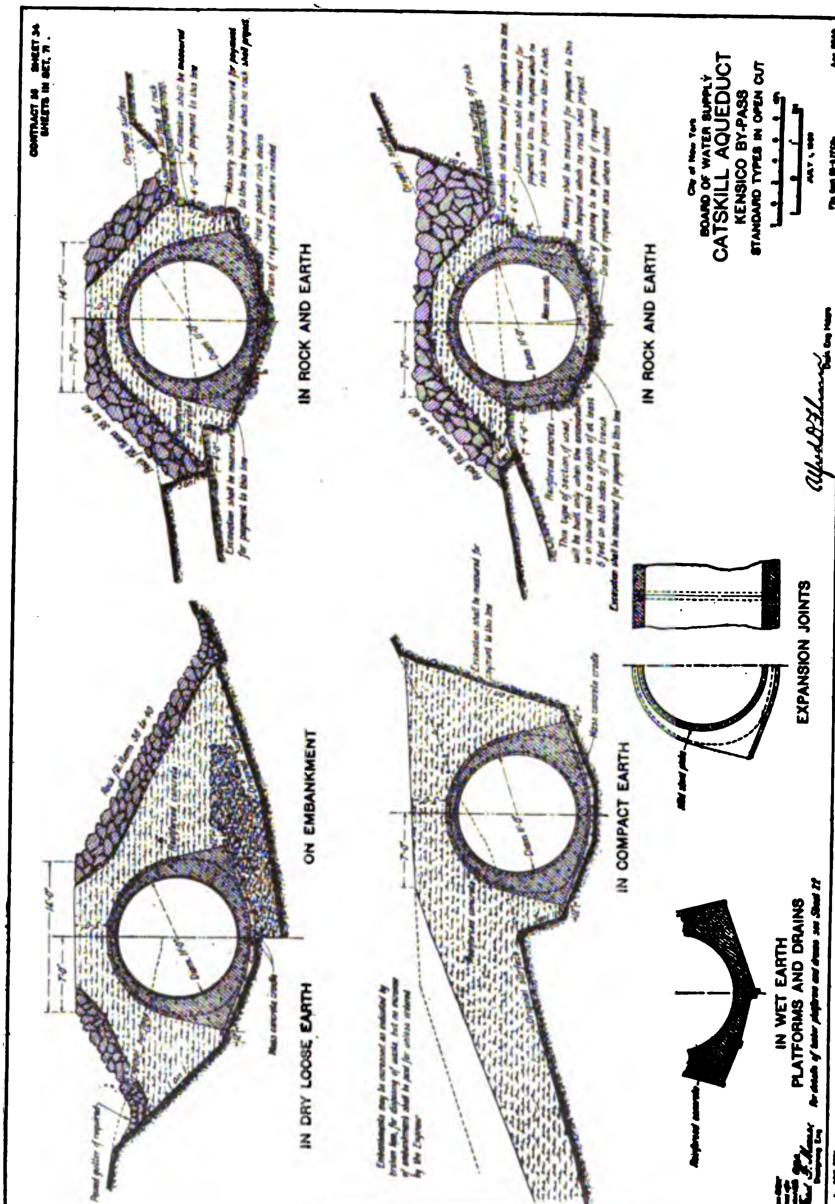


PLATE 175.—Contract 55. By-pass Aqueduct. Cross-section in Cut and on Embankment According to Contract Drawings.

experience here, where the operation was made more difficult by the reinforcing rods, two rows of 1⅛-inch square twisted rods not more than 18 inches apart tied together by ½-inch longitudinal rods 4 feet apart. Difficulty was found at the start in securing a good surface for the invert, there being a tendency for the concrete to become wedged on its way to the center line, forming small banks of stone from which the mortar partially drained out; the result being that between these banks a void was left. On the effluent aqueduct where wooden forms were used and where the diameter is 6 feet more, the trouble was even greater, and here an attempt was made to remedy this by drilling holes in the bottom of the inside forms, to observe whether the mortar was thoroughly rammed below the forms. It was found later that the horizontally reinforcing rods were partly responsible for the separation of the concrete, and when the lowest rod was moved away from the critical point more satisfactory results were obtained. Very great care in ramming was, however, still essential.

Forms for and Concreting of By-pass Aqueduct. The outside forms used during 1910 had only a few removable plates; consequently, on account of the curvature of the inside form there were many places which could not be effectively reached by rammers. The forms were rebuilt the following winter, making all of the outside plates removable except the narrow ribs of the two angles back to back, and one out of every three of the vertical panels. The removable sections were so fitted that they could be readily and securely fastened. This form enabled the concrete to be readily placed and inspected.

The circular inside forms were designed to be used with heavy counter-weighted car to resist the flotation of the concrete. Later it was found that the counter-weighting was unnecessary, this probably being largely due to the reinforcing rods which were supported on blocks resting on the top of the inside form, the blocks being removed as the concrete neared the top. Originally the cars carried jacks to support the forms. Later when the cars were dispensed with, screw-jacks and columns were used to keep the top of the forms from sagging; turn-buckles and ratchet-jacks in a horizontal position drew the sides together, thus giving a true circular shape. The following schedule was followed in concreting the pressure aqueduct:

Concreting By-pass Aqueduct. One shift began work at 4 A.M. to finish the preparation of the forms for the day's cast; at 8 A.M. the regular concrete shift placed the concrete within the forms; and

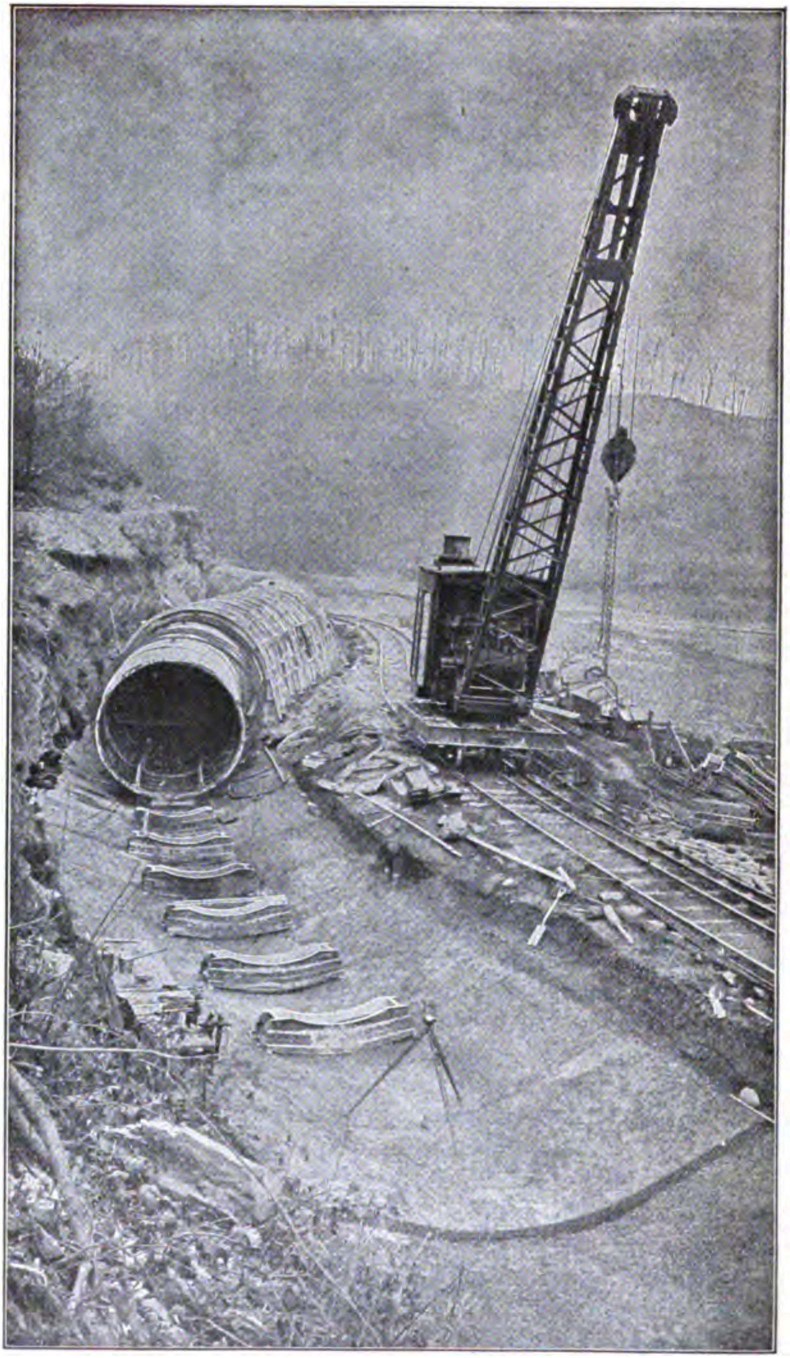


PLATE 176.—Contract 55. Reinforced Concrete By-pass Aqueduct. Shows successive stages of construction, concrete invert, pedestal blocks to support forms, etc.

a third shift coming on at noon took down the back forms over which previously placed concrete had set, passed them through the forms being concreted, and partially assembled them and the reinforcing rods. Usually six 45-foot sections were placed within a week; 1138 feet of this circular aqueduct has been placed within a month. This was very good work.

In earth and soft rock cuts a concrete cradle 7 inches thick was placed over the entire width of the invert to aid in placing the concrete. Upon this concrete cradle narrow, transverse blocks spaced about 7½ feet apart were built to support the form. In a hard rock cut the cradle was omitted. The concrete for the aqueduct itself was dumped in at the top and placed in the space between the invert blocks and under the inside forms by men working through open panels in the outside forms, these panels being closed as fast as the concrete rose in the forms. The 120 feet of Ransome telescopic centering was used for the inside form and 90 feet for the outside. Fillers were used on curves, together with steel bulkheads and steel forms for invert blocks.

Effluent Aqueduct. The effluent aqueduct extending from the lower effluent chamber to Kensico tunnel and south of the tunnel to the Kensico siphon chamber is similar in open-cut construction to the by-pass aqueduct, but is 17 feet in diameter, and is heavily reinforced with two circular rows of bars 1⅜ inches square, spaced not more than 7½ inches apart, with ½-inch longitudinal rods 6 feet apart.

Two kinds of forms, Blaw steel forms provided with a car for moving and to support the forms from sagging, and wooden forms designed on the ground, were used in the construction of this aqueduct. The wooden inside forms were covered with steel plates and consisted of three portions, two of equal size hinged at the top and one smaller section hinged at the lower edge of one of the upper sections. Each section of the form is braced so as to form a bowstring truss. Along with these, outside wooden forms were also used, consisting of wooden ribs in which wooden lagging was placed as the concrete rose. The wooden interior forms were carried near their top on an I-beam supported by two towers, one tower on the finished invert and one on the bottom in advance of the work. Both towers ran on tracks, the I-beams supporting the forms continually, making unnecessary the placing of the form-support blocks necessary with the steel forms. The form was readily moved by folding up the bottom section and pulling the sides of the two upper sections inward and lowering them a short distance

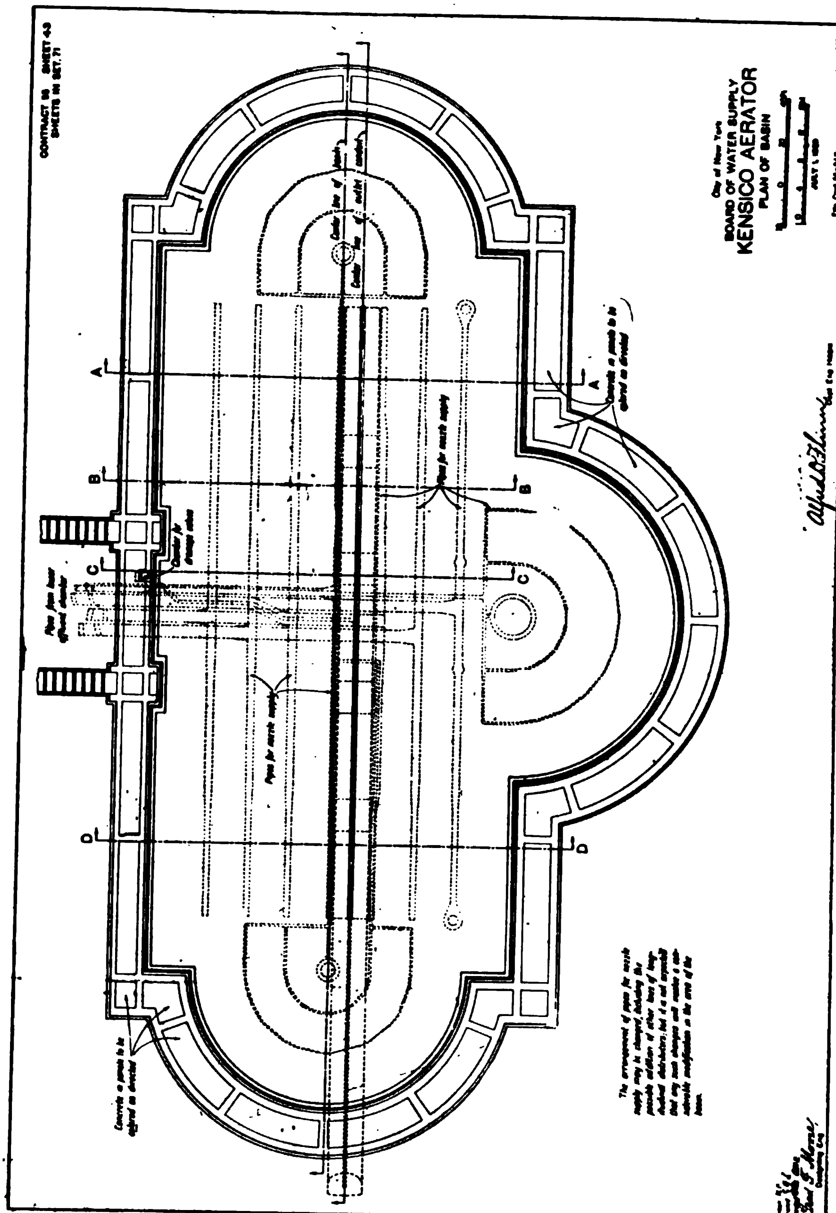


PLATE 177.—Plan of Kensico Aerator, Showing Arrangement of Lines of Pipes to Supply Bronze Nozzles.

onto the supporting I-beams. The steel Blaw forms were supported on the invert blocks as in the case of the Ransome by-pass forms. The effluent aqueduct has also given trouble in the securing of a good invert. The reinforcing rods took up so much room, and the diameter of the inside forms was so great that unless great care was taken the middle 4 feet of invert showed considerable voids. It was necessary to spread the rods and slow up the placing of the concrete at this point and send men to thoroughly spade. Very great care in spading entirely overcame this difficulty.

Difficulties Met in Casting Circular Aqueduct Monolithic. It seems clear from the experience on this contract and in other places that the concreting of circular sections of aqueduct monolithic between transverse joints is attended with difficulties; that additional expense is necessary for forms and that there is danger of securing imperfect concrete below mid-diameter. Experience in pressure tunnels shows that a very good invert and lower half of circular aqueduct can be secured by concreting in three pieces, and that the longitudinal joints give rise to little leakage. It might be argued that in reinforced sections, such as the by-pass and effluents aqueducts, the monolithic construction is stronger, but experience shows that separation of layers is apt to occur due to interruption of work; also that reinforcing steel cannot take up any reasonable working stress before the concrete shows incipient cracks. In the construction of portions of Venturi meters of circular reinforced sections, the invert has been cast separately from the upper portion, the longitudinal joints being protected against leakage by steel plates. The resulting aqueduct is very satisfactory. At the Putnam siphon the invert was cast in advance, after which the upper half, about two-thirds of section, was concreted, using a wooden collapsible form. All the joints were provided with 6-inch steel plates to act as water stops. This section was heavily reinforced.

CHAPTER XVI

KENSICO DAM AND APPURTENANT WORKS

Works and Prices. Contract 9. This contract was awarded to John C. Rodgers, J. M. Rodgers, and J. J. Haggerty, December, 1909, but was assigned, September, 1910, to H. S. Kerbaugh, Inc. The total bid price was $7,953,000. Some of the items are as follows:

Earth excavation, Class A, B, C, D	1,340,000 cu.yds.	$0.50 to 2.00 per cu.yd.
Rock excavation under dam without blasting	40,000 "	1.50 per cu.yd.
Refilling and embanking	1,340,000 "	0.20 to 0.55 per cu.yd.
Surface dressing and grassing	100,000 "	0.50 per cu.yd.
Portland cement	900,000 bbls.	1.50 per bbl.
Mass concrete	37,500 cu.yds.	5.25 to 5.75 per cu.yd.
Cyclopean masonry	900,000 "	2.65 per cu.yd.
Concrete blocks	60,000 "	7.50 per cu.yd.
Dimension stones	24,700 "	23.05 to 24.54 per cu.yd.
Steel for reinforcing concrete	1,250,000 lbs.	0.035 to 0.04 per lb.
Face dressing of Quarry face work, Bull-pointed work, Rough pointed, Fine pointed, Four-cut work, Six- to 8-cut work	410,000 sq.ft.	0.13 to 1.00 per sq.ft.

Magnitude of Contract 9. Contract 9 is the second largest contract of the Catskill water system, and because of its complexity, a period of ten years is allowed for its completion, and work will be under construction several years after the Catskill Aqueduct is bringing water into the City through the City aqueduct. This is made possible by the By-pass aqueduct (Contract 55), which permits Kensico reservoir to be cut out.

Location of New Kensico Dam. Originally it was proposed to build the new Kensico dam just below the old dam forming Lake Kensico. This had the advantage of not disturbing the old reservoir and the old dam so that water could continue to be delivered through the 48-inch pipe forming the Bronx conduit to Williamsbridge

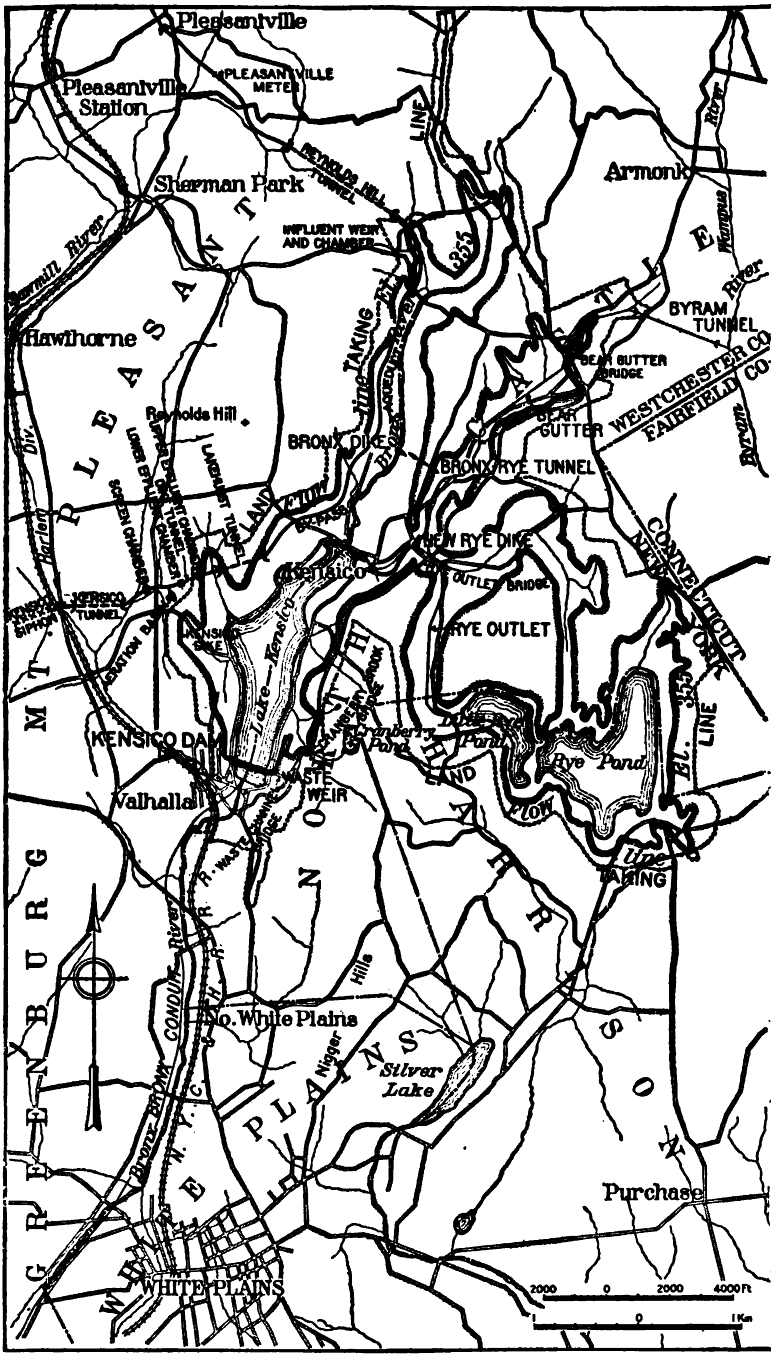


Plate 178.—Contract 9. Map of Kensico Reservoir and Adjacent Structures, such as Dam, Influent Weir, By-pass Aqueduct, Effluent Chamber, Aerator, etc.

reservoir supplying a portion of Bronx Borough. Further consideration showed that it would be dangerous to make the large and deep excavation necessary below the old dam for the foundations of the much higher dam to be built, and a favorable site having been discovered by borings above the old dam it was decided to drain Lake Kensico and build the new dam just upstream from the old one. This made it necessary to build temporary works to supply the Bronx conduit, as, pending the delivery of Catskill water, all the water which can now be obtained is urgently needed. All this work is provided for under Contract 9, as shown on Plate 178.

Temporary Water Works to Supply Bronx Conduit and Highways. A temporary reservoir known as New Rye reservoir was formed by an earth embankment 475 feet in length, 50 feet high, with a wooden core wall. This embankment, known as the New Rye dike, is also supplied with a waste weir and waste channel. To secure the flow of the Bronx River, this stream is dammed by an embankment about 460 feet long with a maximum height of 42 feet, and also contains a timber core wall. This embankment, known as the Bronx dike, is also supplied with a waste weir and waste channel. The water impounded by this dike is diverted into a short tunnel, piercing the divide to New Rye reservoir. This, known as the Bronx-Rye tunnel, is only 655 feet long. To carry the water from the New Rye reservoir 10,634 feet of 36-inch riveted steel pipe line were laid to the Bronx conduit below the old Kensico dam. The temporary reservoirs will have about 5,000,000,000 gallons available capacity and cover an area of 709 acres. In order to guarantee a supply for the Williamsbridge reservoir an outfit of turbine pumps was installed at Jerome Park reservoir, so that a supply of Croton water could be pumped into the Williamsbridge reservoir in case of shortage of the temporary supply.

Because the new reservoir is to be so much larger than the present reservoir, it was necessary to build also several miles of new highways. These highways were constructed above the flow line of the new reservoir and across arms of the reservoir on permanent bridges, the most important of which is the Rye Outlet bridge, which crosses at a height of about 110 feet above the bed of the reservoir and has a length, including approaches, of about 924 feet, with five reinforced concrete arches. These auxiliary works occupied practically the first two years of construction work.

Swamp Covering. The contract provided that several hundred acres of swamp land and shallow borders on the sites selected for the reservoir be covered with clean earth and sand. This covering was obtained by shovels working in various borrow-pits and loading narrow-gauge cars, which were dumped from the tracks directly into place.

Plant for Rye Outlet Bridge. A power plant was installed near the Rye Outlet bridge and consisted of three locomotive boilers with a combined capacity of 230 H.P., two Ingersoll-Sergeant compressors of 3600 cubic feet free air per minute combined capacity, and a generator for furnishing light for the Bronx-Rye tunnel. From this plant air was furnished for drills and derricks on the Rye Outlet bridge, to drills in operation along the highway to the north of the bridge and in the Bronx-Rye tunnel.

Rye Outlet Bridge. The Rye Outlet bridge is an imposing structure of five spans, the central span 128 feet 7 inches, two intermediate spans 127 feet 7 inches, and end spans 124 feet 7 inches, the total length of bridge, including approaches, being 924 feet. The maximum clear height of bridge is 110 feet. Each span consists of two concrete arch ribs, reinforced by four steel ribs of fabricated angles and bars, in addition to which there are in the entire bridge nearly 1800 separate steel bars of 275 different lengths and sizes. For the construction of this bridge a special concrete plant was installed. A quarry was opened a few hundred feet north of the bridge, and the stone crushed in a near-by plant and conveyed to bins over the mixer on a trestle about 265 feet long. The sand bin over the mixer was filled by a 90-foot bucket conveyor, the sand being delivered in wagons.

Construction of Rye Outlet Bridge. Two Ransome concrete mixers at the plant discharged into buckets operated as elevators and raised above the false work for the superstructure of the bridge. The concrete there was discharged into cars and was pushed along on a track on the false work and deposited in place through chutes. The main element in its construction was the forms required for the large spans. These forms settled only .03 to .06 of a foot after the arches were cast. To remove all form marks and to provide a more artistic surface a 3-inch mortar face, later tool dressed, was placed on the exposed sides of the bridge. This was at first obtained by the aid of steel diaphragms placed edge to edge within 3 inches of the forms and pulled up from time to time as facing and concrete were placed around them. It was found practically impossible to keep these diaphragms in place and the use of ½-inch square-mesh wire was resorted to. The facing mortar was mixed rather dry and rammed down between the netting and the form fast enough

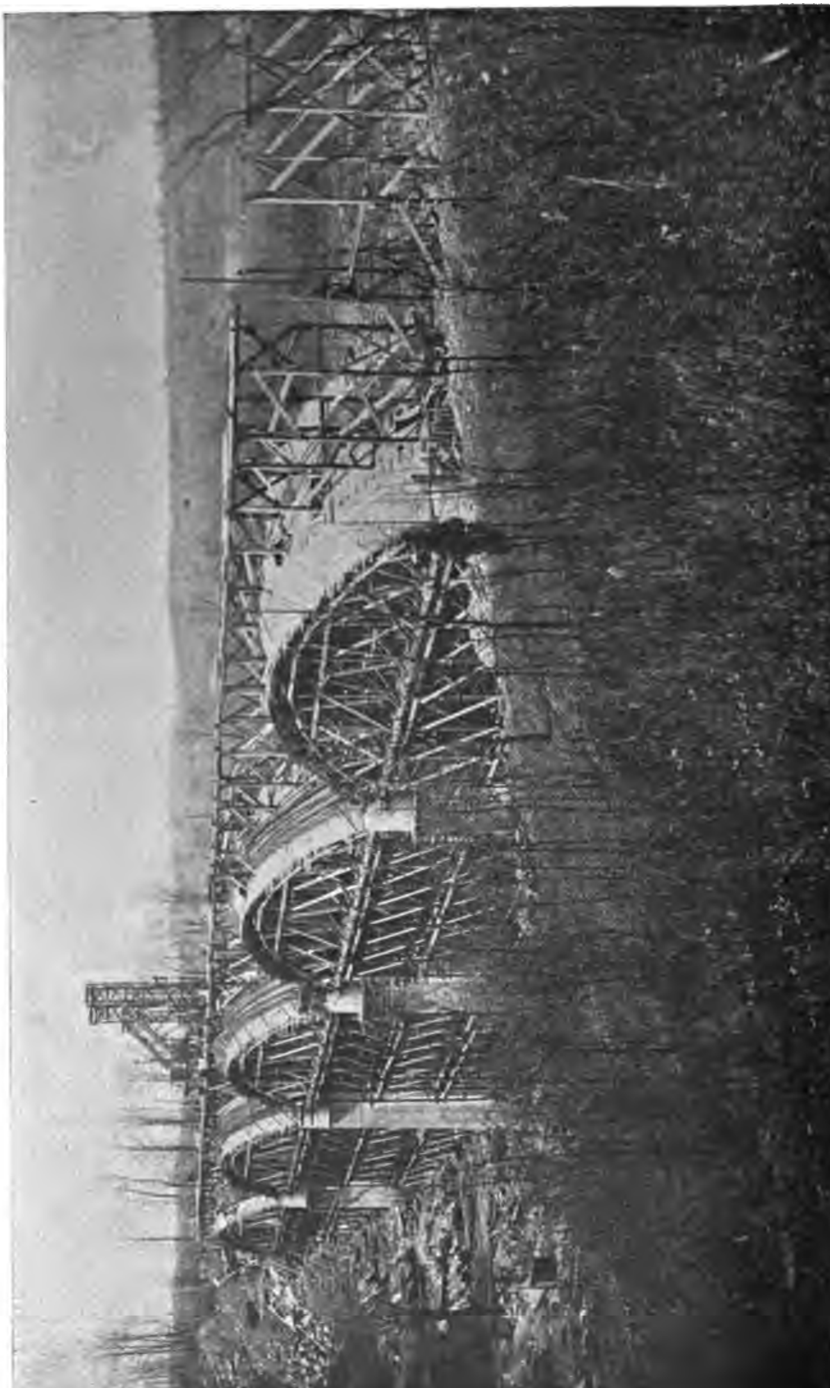


PLATE 179.—Contract 9. Rye Outlet Bridge; Forms in Position. General View Showing Tower for Raising Concrete, Tracks, etc.

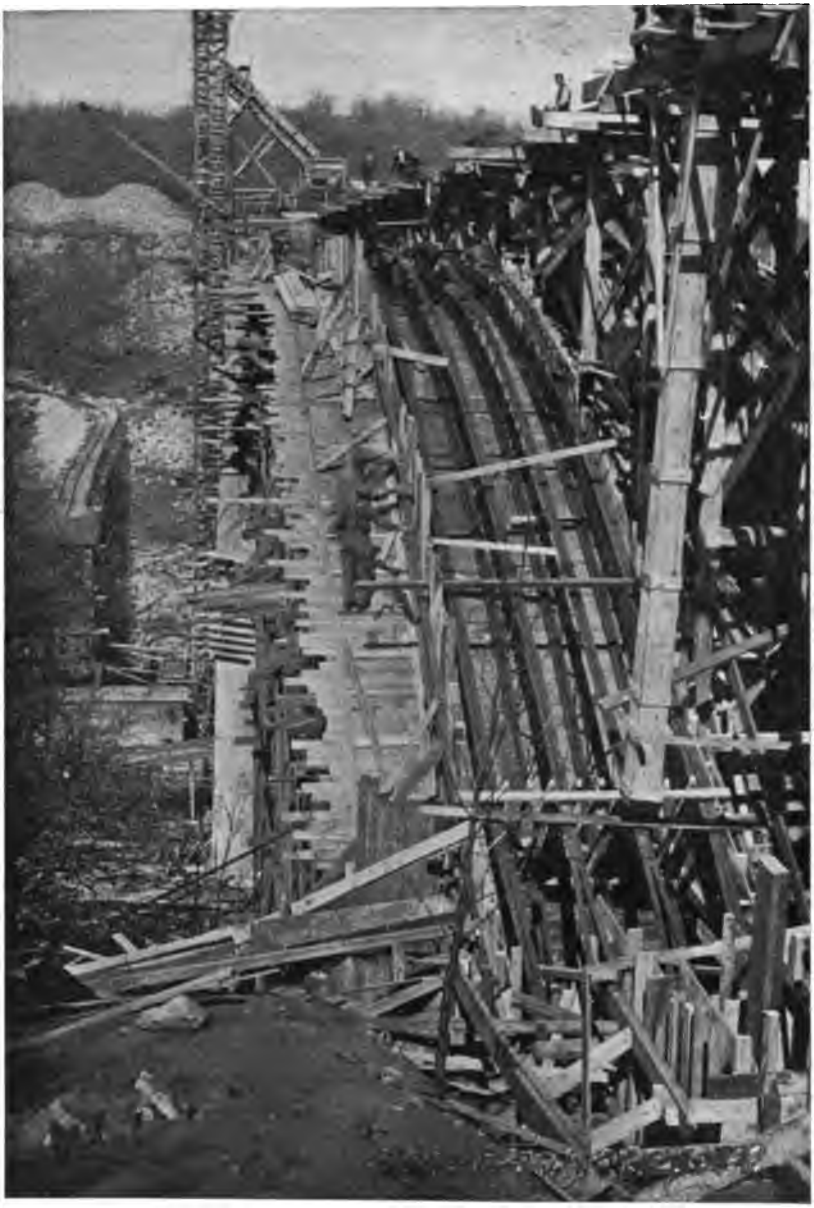


PLATE 180.—Contract 9. Rye Outlet Bridge in Construction. Tower and Steel Reinforcing Ribs in Position.

to keep slightly ahead of the concrete. After the forms were moved the facings were dressed down with hammers and axes.

Kensico Dam. Kensico dam will be a much larger masonry structure than the corresponding portion of the Olive Bridge dam, but will be of very similar construction as to cyclopean masonry, concrete blocks, expansion joints, inspection wells, drainage wells, etc., but for architectural effect the exposed face will be of granite ashlar. It will have a maximum height of about 170 feet above the present river bed, but will extend 130 feet further to solid ledge rock, which will make it at the maximum about 300 feet high, or about 50 feet higher than the Olive Bridge dam. It will be about 1830 feet long, or nearly twice the length of the masonry portion of the Olive Bridge dam. Extending from hillside to hillside the dam will not be flanked by long stretches of dikes or core wall dams, such as are used to form the Ashokan Reservoir. The drainage area of the Bronx River being very small in proportion to the area of Kensico reservoir, a waste weir only 50 feet long, built across the shallow channel near the easterly end of the dam, will suffice. A small gate chamber will be installed in the dam from which the 48-inch Bronx conduit can be supplied. It is expected that considerable cut-stone masonry will be used for the exposed surface of the downstream face of the dam. An effort is to be made to develop the architectural possibilities of the dam and its setting, as this locality is very accessible by good roads from New York and other communities near by. The reservoir itself, being of very irregular outline containing islands and numerous arms and surrounded by picturesque hilly country, will have the appearance of a natural lake and will probably be maintained at a nearly constant elevation.

Kensico Reservoir. This reservoir is to have an available capacity of 29,000 million gallons and its flow line will be at elevation 355; 110 feet above old Kensico Lake. As described under Contract 55, it will be supplied by a weir at the head of the by-pass aqueduct, while 3 miles below the lake is to be drained through an effluent channel to the effluent aqueduct. The reservoir will contain a supply for about sixty days at maximum draft and will serve to tide the city over an emergency occasioned by a break in the aqueduct above this point, or what is more likely, enable inspection and repairs to be made from time to time on different parts of the aqueduct. The Kensico reservoir will also act as a large settling basin for the Catskill water, and in addition, all water drawn from the reservoir will normally be aerated. Between Kensico reservoir and Hill View reservoir there are only 15 miles of

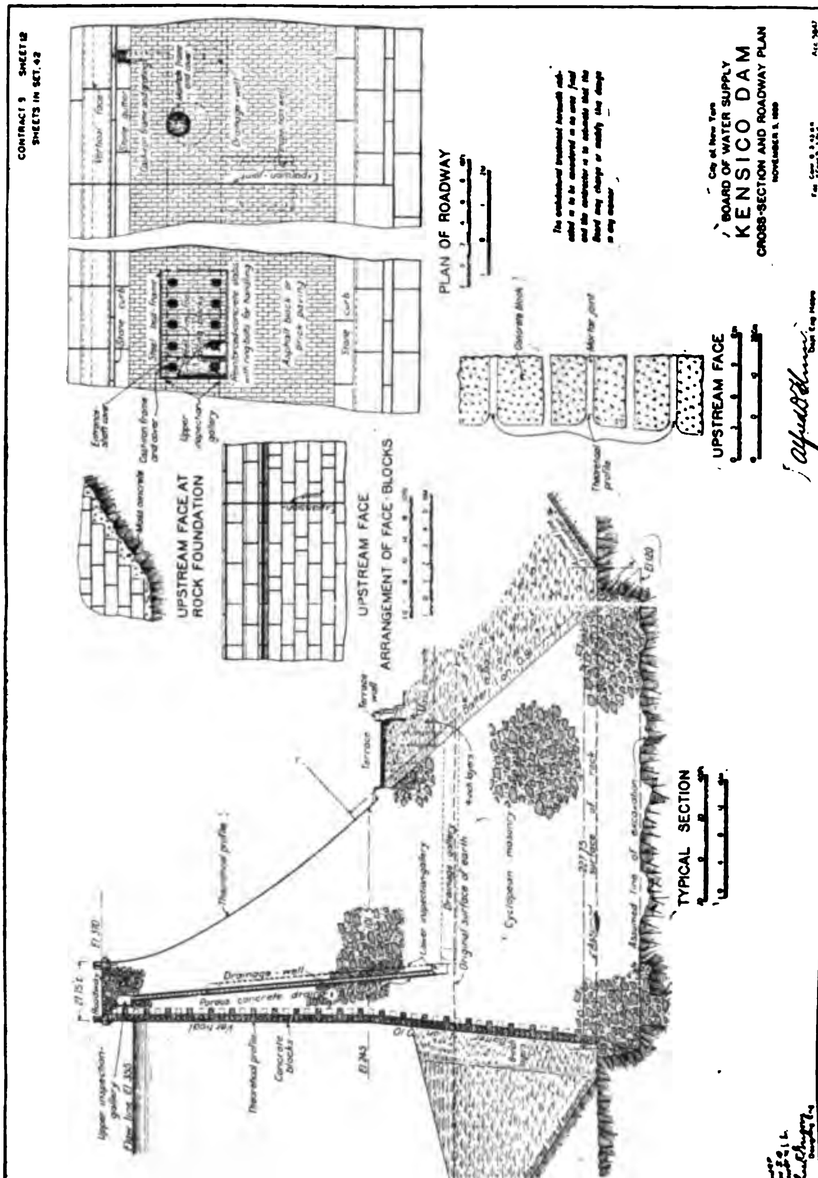


PLATE 181.—Contract 9. Kensico Dam. Typical Section, Showing Inspection Galleries, Drainage Wells, Face Blocks, Roadway, etc., According to Contract Drawings.

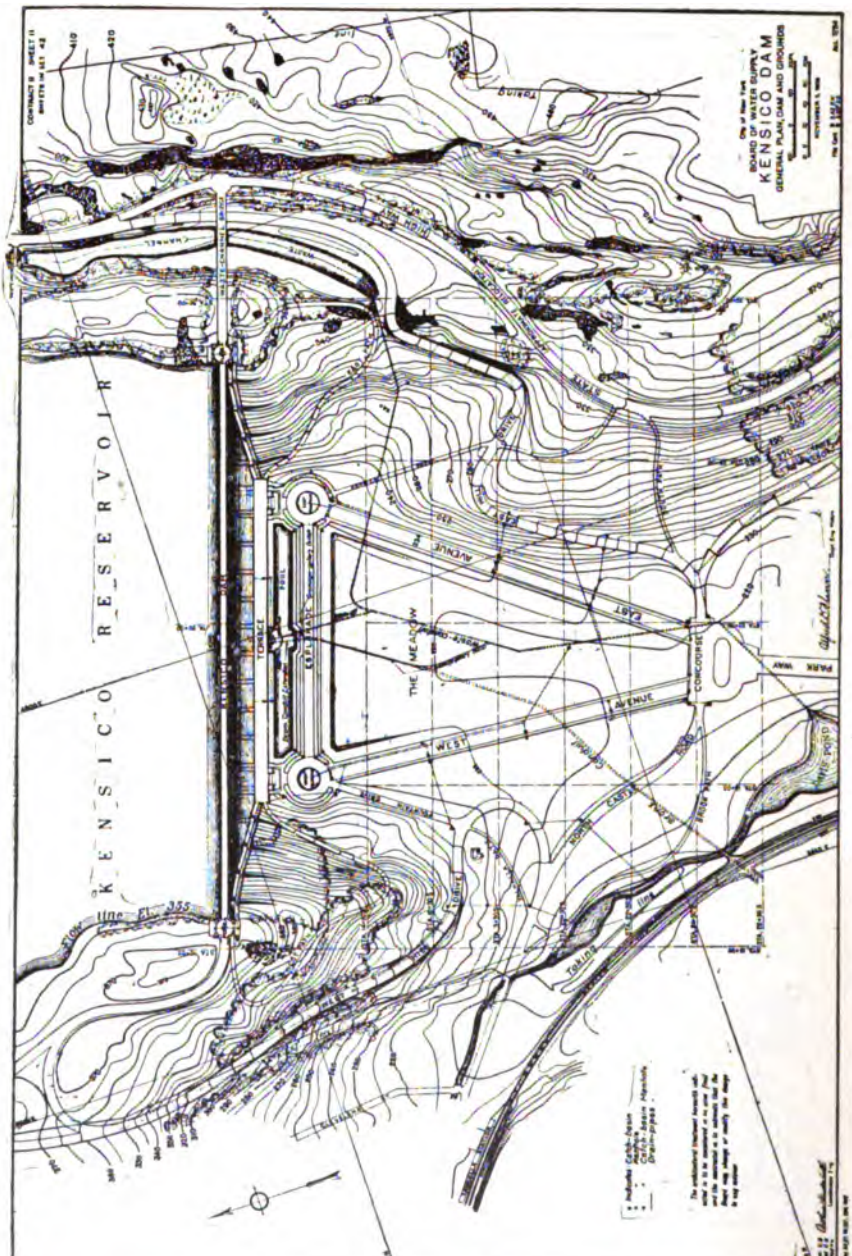


PLATE 182.—Contract 9. General Plan of Kensico Dam and Grounds.

aqueduct against 75 miles above, and therefore there is much less likelihood of a break occurring between the reservoirs than above Kensico.

Power Plant at Dam. For construction there is at the top of the hill near the east end of the dam a compressor plant consisting of two Laidlaw-Dunn-Gordon compressors of 1500 cubic feet capacity, belted to two G. E. 300-H.P. induction motors, used to supply air to points at or near the dam. This plant is capable, however, of furnishing only a small portion of the power needed. A high-tension line was built along the aqueduct from New York City so that power can be secured from electric companies in New York.

It is planned to use electricity as a source of power as far as practicable, only shovels and traction engines being operated by steam.

Drawing Down of Lake Kensico. In September, 1911, water was sent through the Rye pipe line from the newly completed Bronx-Rye reservoir, and the normal draft from Lake Kensico soon drew down the water so that a large part of the remainder could be drawn off through the blowout in the old dam, and the pool which remained was pumped down, and quantities of fish gathered up in seines were transferred alive to other city reservoirs. An earth dike was built across the old lake bottom a short distance above the foundation for the new dam. From the end of this dike a ditch was dug to the old blowoff, a pump was installed, and the site of the dam unwatered.

Flume for General Drainage and Waste Conduit. To permanently carry during construction the drainage from above the dam a wooden flume was constructed skirting the east bank, so that where it crosses the site of the new dam it will be entirely in rock at about the final depth of excavation. This flume continues through the old Kensico dam and into the new waste conduit. This conduit is built of concrete and is of horse-shoe shape 7 feet 6 inches high by 8 feet 3 inches wide, and carries the waste from the new reservoir underneath the plaza below the dam to an outlet into the Bronx River. The excavation for the flume was made by two steam shovels which worked toward each other along the center line of the flume and breached the old Kensico dam, which was widened to provide room for a railroad.

General Plan of Construction. The general method of work at the Kensico dam both in excavation for foundations and placing of masonry is very different from that employed at the Ashokan dam. The main tool at the Ashokan dam was the cableway which was employed to remove material from the foundation of the dam in the Esopus gorge and to transport all the masonry placed by the derrick on and around the dam. At Kensico the railroad is the main agent of transportation and the cableways merely auxiliaries. The excavation at Kensico was nearly all loaded into cars by steam shovel and hauled over standard-gauge track directly to the fills. The masonry will similarly be carried out on the dam on trains operating on several lines of tracks and placed by traveling cranes operating on parallel tracks. Two cableways of 1860 feet span will be used mainly to raise the tracks on the dam, as will be explained.

Method of Excavation. Some excavation on the side-hill portion to the west was removed by orange-peel bucket and hand loading into skips and placed into a fill immediately to the south, but the bulk of the material was removed by standard-gauge 8-yard cars, loaded by three 70-ton Marion steam shovels. The shovels worked themselves down about 80 feet below the original surface of stream bed to near the lowest point of rock, the loaded trains being hauled up an incline by two hoists and then taken to large fill south of the dam by dinkies. The shovels for a considerable depth were excavating a very fine sand (97 per cent through a No. 50 sieve), wet but not water-bearing. This sand could be but imperfectly drained by sump and ditches.

Shovels Operating on Rafts in Soft Ground. It was necessary in order to keep the shovel from becoming mired to use rafts of three 14-inch timbers 24 feet long securely bolted together. These were placed transversely close together in front of the shovel and the shovel moved onto them, submerging the platform in less than five minutes. This made such a steep grade for the advancing shovel that it was helped by a locomotive crane, which also placed and moved the heavy platform.

Rock Excavation. The rock when exposed was blasted and removed by steam shovel; and also by traveling hoists which moved the hand-loaded skips. A very interesting formation of limestone (a few hundred feet wide), known as the "Inwood," was uncovered. This bed, found also under the Croton dam, under the Harlem River, and even as far south as Delancey Street at the lower end of Manhattan Island, separates the old Fordham gneiss from the younger Manhattan schist. The rock dips about 55 degrees to the west and strikes about at right angles to the dam. The Manhattan schist contact is very sound, but that between the limestone and gneiss is much decayed, the gneiss breaking up into a rusty light-

Plate 183.—Contract 9. Kensico Dam Foundations. Cableway towers for span of 1950 Feet. Excavation mostly removed by steam shovels. Remains of old Kensico Dam at Left.

clay powder and the limestone into a sugary-white sand. At this writing the contact has not yet been thoroughly explored.

Electric Power and Drills. The work at Kensico dam is to furnish the largest and most varied application of electric power to construction work for the Catskill supply. An electric power line was built over the aqueduct right-of-way clear to Yonkers (about 4 miles) and current at 66,000 volts furnished by the New York Edison Company. The current, of course, will be transformed at the dam site and used to operate air compressors, hoists, lights, drills, etc. The compressor plant which was formerly used at the Peak tunnel, Contract 11, was put in operation and furnishes power to many drills, but the bulk of the rock drilling is being done by electric drills.

Temple-Ingersoll Electric Air Drills. After investigation, the contractor decided to install Temple electric air drills, both for work on the dam foundation and at the quarry, the reason for installing these drills being to save power, as it was estimated that they operate for about one-half the power charge of the ordinary air drills. The Temple-Ingersoll drill is operated by a pulsator which is a sort of compressor carried on a small wheeled carriage near the drill. The pulsator contains one or two long cylinders in which a motor-driven piston reciprocates. Each end of the cylinder connects with a flexible hose about 15 feet long, which leads to the valve chamber of a simplified air drill. The pulsator alternately furnishes air to each side of the piston of drill and the same air is used over and over again in a closed circuit.

The contractor has already put into use 35 F5 Temple electric air drills and states that they drill hard gneiss a little faster than the regular air-operated drills.

Militating against the undoubted advantages of the Ingersoll-Temple drill is its high unit cost per drill and the handicap (in certain places) of the pulsator carriage power lines, etc. Its great single advantage is that (where abundant electric power is available) the amount of drilling done can be increased indefinitely and will not strain the capacity of the compressor plant.

Temple Electric Air Traction or Deep Hole Drill. To drill deep holes at the quarry, four large traction drills mounted on wagons similarly to the familiar well or churn drill were installed. They, in fact, drill holes of the same type as the well drills, up to 40 feet in depth, tapering from 5½ to 4 inches in diameter.

The base of the machine is a heavy steel wagon mounted on flat wheels; forward is a heavy turntable carrying the drill, pulsator,

PLATE 184*a*.—Contract 9. Deep Hole or Traction Drill. Temple-Ingersoll Electric Air Drill Mounted on Front of Machine; Entire Apparatus Motor Driven. Drills holes up to 30 feet in depth for deep cuts in quarry.

PLATE 184*b*.—Contract 9. Quarry and Temple-Ingersoll Electric Air Drills at Work. Pulsator for drill in foreground.

header, etc., together with a 20-foot derrick, which contains the guides for the drill and serves to raise and lower the heavy steel into the holes.

The drill, mounted on the forward end of the derrick like a pile-driver hammer, is of 7-inch cylinder diameter and 7-inch stroke, striking 350 blows per minute. It is connected with the pulsator by iron pipes provided with flexible joints at the drill. The pulsator is operated by a 12-H. P. motor, which also by clutches can be used to drive the feed screw for the drill hoists, and for raising and lowering the steel, etc. The motor also operates a winch which moves the apparatus by aid of ropes attached to a dead man. The machine may also be moved by horses attached to shafts. The drill steel hoist operates at a speed of about 46 feet per minute; the feed screw operated from the motor can drive the drill downward at maximum rate of about 5 feet per minute and can be reversed at will or slowed down to any desired speed. The drill is mounted so as to move on a semicircle 10 feet in diameter. The crew consists of two men.

Speed and Cost of Operation. It is said that under test this machine has drilled 104 feet of hole in one shift where 10 to 15 feet by ordinary well drill would be considered fast. Also that the power cost of a day's run is only from 30 to 75 cents per day. Workmen operating the drill during the fall of 1912 stated to the author that they were drilling one 30-foot hole per day; an adjoining well drill was only able to put down about 10 feet of hole per day in the same rock. The large steels are sharpened by a Leyner sharpener. To clear the hole of cuttings blow pipes supplying water to wash out the holes are used.

General Usefulness of Deep-hole Traction Drills. There would seem to be a great future for a traction drill of this class, as the well drill has come to be very extensively used for quarries and all kinds of rock cuts. Air traction drills mounted similarly to the Temple air deep-hole drill, have been very successfully used at the Livingston channel, Detroit, Mich., and elsewhere by Mr. Locher, so it would seem that, with its economy of power and handiness, this new traction drill should have extensive use.

Drilling at Quarry. The quarry, conveniently located near the crushing plant, consists of a great hill of Yonkers gneiss, which has been stripped of its overburden and drilled over a considerable area with holes systematically placed in rows and drilled 15–20 feet in depth by regular Temple-Ingersoll drills. Rows of holes 30 feet deep have been drilled by the Temple-Ingersoll traction drill to give a start for the steam shovel. The holes are shot in batteries of many hundred, loosening up many acres at a time so as to be handled by 90-ton steam shovels. It is planned to obtain cyclopean, concrete and dimension stones from this quarry.

The above quarry is outside of the city land and has been connected by a track with the dam which includes a steel highway bridge and a timber trestle across the spillway.

First Masonry to be Laid. Although no masonry in the main dam will be laid before the spring of 1913, the plan of operation is now pretty well worked out. The deep gorge, which has been dug out about 200 feet wide and 130 feet deep, will be filled with masonry by derricks. This will take about 70,000 cubic yards, and will give a practically level bottom, upon which will be laid six tracks parallel to the axis of the dam.

Tracks on Dam. The two interior tracks will be of wide gauge for travelers; on each side of them will be a pair of standard-gauge running tracks. When the masonry reaches track elevation the track will be elevated 20 feet, resting on concrete piers incorporated in the masonry of the dam. The two cableways will be used to set the concrete pier blocks for the tracks and to raise the track in sections, but not for the direct handling of masonry as at Olive bridge.

The concrete will be mixed in Hains mixers over the tracks, and together with cyclopean stone, concrete blocks and dimension stone will be hauled on flat cars to be placed by the derricks on the traveler. Each traveler will be equipped with two electrically operated derricks and there will be eight travelers working in batteries of four, facing each other so as to build a section between adjacent transverse expansion joints. Two of the tracks will be used to bring in blocks and will for that day serve a group of four travelers setting blocks. The other two tracks and four travelers will be employed in placing cyclopean masonry. The operations will be reversed on the following day. It is expected that this plant will be capable of placing 1500 cubic yards of masonry in one shift of eight hours, which is beyond what was accomplished at the Ashokan dam.

The Block Yard. The filled-in area below the dam was availed of for a block yard. A plant containing overhead bins, fed by a cantilever projecting over an adjacent material track, fills steel forms directly from a rotary mixer. The plant spans several lines of forms and moves on tracks.

Crushing Plant. The plant installed at the quarry is probably the largest ever placed on contract work. Rock is drilled with pneumatic machines capable of boring a 5-inch hole to the depth of 30 feet. The blasted stone is handled by 90-ton steam shovels with 4-yard dippers, loading directly into 8-cubic-yard cars hauled in trains by 40-ton locomotives. The cars are hauled to the crushing plant and dumped into a chute leading directly into the initial crusher, which is a Blake jaw crusher, probably the largest of its type yet made. This crusher is designed to take stones as large as can be handled by the steam shovel, thus saving a great deal of redrilling and mud-capping of stones too large for ordinary crushers.

Largest Jaw Crushers to Date. The initial crusher has a clear opening of 5′×7′. The rock is here reduced to a size of about 9 inches and finer, and then passes over a grizzly with 4½-inch openings. The under size goes directly to the elevator, while the over size is run through a second crusher of the same type with an opening 3′×6′, reducing it to 4 inches and finer, and passes together with the under size from the grizzly to an elevator which raises it to a 7′×30′ screen. This screen removes material below ¼ inch, to be used for sand and stored separately, while the coarse aggregate, between ¼ and 2½ inches, is distributed by a 30-inch belt conveyor into a 10,000-ton storage bin. The over size from the screen is recrushed by a 60″×30″ roll. The storage bins are constructed over tracks so arranged that the standard-gauge cars can be readily loaded from many points. The main bucket elevator has steel buckets 40 inches wide, 18 inches deep and 19 inches projection. The large crusher with the jaw opening 5′×7′ is designed to take a stone weighing 10 tons and reduce it within one minute. It is constructed of cast steel with the exception of the two large flywheels, and has a total weight of 450,000 pounds. The flywheels are 12 feet in diameter and weigh 15 tons each. The swinging jaw is 13′×7′ wide and weighs 74,000 pounds. The wearing plates are interchangeable and of manganese steel.

Crusher Rolls. The 60″×30″ heavy-duty roll is said to be one of the largest ever built and has a designed capacity of 300 cubic yards per hour, crushing from 4 inches down to 2 inches. Rolls are about 5 feet in diameter with 30-inch face, and the shafts are 16 inches in diameter, and the frame alone weighs 30 tons. The large crusher is driven by a 300-H.P. induction motor, the smaller crusher by a 150-H.P. motor, and the crushing roll by a 100-H.P. motor, the elevator and screen by a 50-H.P. motor. The two belt conveyors are operated by 5- and 15-H.P. motors.*

Comparative Size of Kensico Crushers. The only crusher of larger size is that installed at Tomkins Cove in 1910. This is an Edison roll capable of taking stones 10′×10′ up to a weight of 20 tons, and has a rated capacity of 3000 tons per hour, although the entire capacity of the plant is less. McCully and Gates gyratory crushers have been built to take stone of 10 tons, 42″×96″ and 48″×120″ respectively, while the Blake jaw crusher described will take stones of 10 tons up to 60″×84″ and crush 700 tons per hour, about the capacity of the gyratory crushers mentioned.

Temporary Dikes. An interesting type of timber-core wall dike was developed on Contract 9 for the temporary dikes. Instead of vertical 4-inch groove-and-spline sheeting supported by horizontal wales, the contractor used triple-ply sheeting laid horizontally with vertical wales. Each ply is made of 1½-inch boards, the two outside layers dressed on one side and the middle layer on both sides. The boards are so placed as to break joints 3 feet horizontally and 1½ inches vertically, forming a tongue-and-groove effect. The wales are spaced 7 feet apart and are bolted to the sheeting every 2 feet. The advantage of this construction is that the core wall can be carried up as the embankment grows, and is always accessible to a man standing on the ground. This type of core wall is both easier to construct and more satisfactory than one built with vertical boards or planking.

The new Rye dike with timber-core wall has a top width of 20 feet with a slope of 1 on 2½ to the water side and 1 on 2 on the other side, constructed in 6-inch layers, with riprap on both slopes.

Labor Camp, Welfare Work. As the work is to take ten years the camps are substantially built with many conveniences of a city. In addition to physical comfort other needs have been attended to. An immigrant school was established by the North American Civic League. This house, although of large size, was soon outgrown, and an assembly room with a stage and dressing rooms was added, and the old schoolrooms turned into club and reading rooms. There are kindergarten classes every day, and practically every child in camp of suitable age attends. In the afternoon there are sewing and housekeeping classes for the women. In the evening there are two-hour sessions for the men, who are taught to read and write English and also such subjects as will fit them for citizenship. These

* The plant is described in detail in *Engineering News*, Feb. 2, 1912.

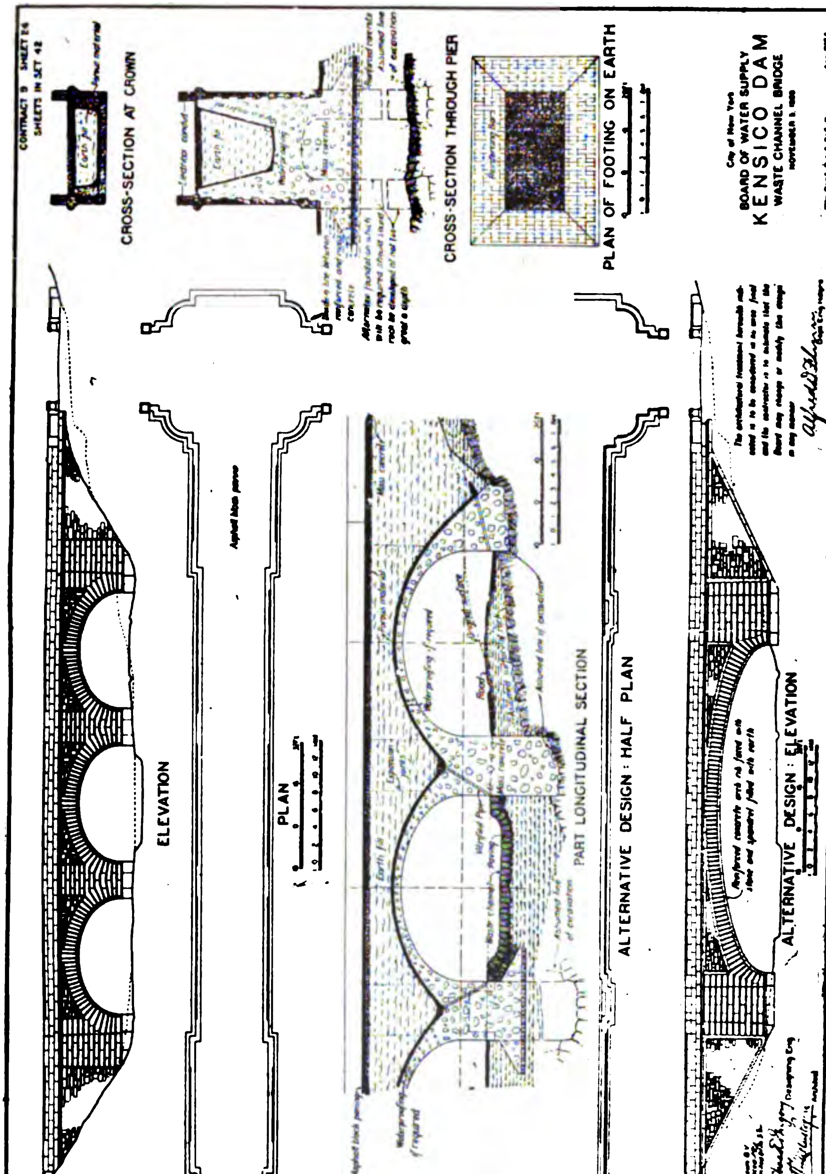


Plate 185.—Contract 9. Waste Channel Bridge at Kensico Dam, from Contract Drawings.

night classes are in charge of teachers who understand the various languages and dialects and are very well attended. The Russians in camp are particularly quick in learning to read and write English. At the assembly room dances are given, also moving picture shows and musical selections rendered on the phonograph. There is also a playground for the children. This work has done a great deal to improve the general tone of the camp and the relationship of the men toward each other and toward the contractor.

CHAPTER XVII

WHITE PLAINS DIVISION

CONTRACT 52

Location and Work Included in Contract 52. Contract 52 is situated in Westchester County near Elmsford, and lies conveniently between the Harlem and Putnam divisions of the New York Central Railroad and in general parallel to them. It comprises several stretches of cut-and-cover aqueduct, aggregating 2.8 miles, and three tunnels—Eastview tunnel, 5400 feet long, driven from two portals, and a central construction shaft 2040 feet north of the south portal; Elmsford tunnel, 2375 feet long; and Elmsford tunnel south, 950 feet long. Between these stretches is Elmsford steel pipe siphon, a portion of Contract 68. At the south portal of Eastview tunnel a gate chamber is to be built to provide connection with a proposed filtration plant to be built under another contract.

Contract Prices. This contract, aggregating $2,852,000, was let to the Pittsburgh Contracting Co., January, 1910. To give some idea of the prices obtained, the following is given:

Open-cut excavation	$0.55 per cu.yd.
Refill and embankment	0.30 "
Concrete masonry for cut-and-cover aqueduct	5.25 "
Rock excavation in tunnel	5.50 "
Timbering in tunnel	50.00 per M ft. B.M.
Concrete in tunnel	6.00 per cu. yd.
Portland cement	1.55 per bbl.

Additional price for compressed air work in tunnel, excavation $1, timbering $2 per M feet B.M.; concrete $1 per yard. Estimated cost of cut-and-cover aqueduct is $68 per foot; of grade tunnel $130 per foot.

Sanitation. As the aqueduct line crosses through several small watersheds used by neighboring towns, also part of the Bronx watershed which supplies some water to the City of New York, the sanitary requirements were very strict, so that the main work at the beginning was the establishing of camps. Three camps were established, known as Eastview, Bonner and Elmsford, and of all these, Eastview camp is typical.

This camp was located on land taken for the Eastview filters. It consisted of an office, eight barracks accommodating 184 men, two hospitals, a washhouse and outdoor kitchen. These buildings were lighted by electricity and heated by stoves. The camp was provided with a water supply from a spring. A sewer system conveyed wash water from the camp into a settling tank which in turn discharged through a Wagner 4-inch automatic siphon onto a small filter bed, effluent from the filter bed draining into a brook. All organic matter from the camp was burned in incinerators.

General Plant. A standard-gauge track was laid from a point on the Putnam division of the Central Railroad north of Elmsford to the central crusher and mixing plant. This road was $1\frac{1}{4}$ miles long and passes through a sand pit, and all supplies and sand were hauled over it. From the crusher, a single track on downhill side of aqueduct was extended northward 3700 feet to the Eastview tunnel and southward 5000 feet to the Elmsford siphon. The road was equipped with standard-gauge locomotives and side-dump cars. Four Interstate locomotive cranes were installed. These cranes are self propelling over the standard-gauge track and were used for excavation, placing concrete and back filling. When excavating they were equipped with drag or scraper buckets; also for some classes of digging with Hayward orange-peel buckets.

Compressor Plant. For the tunnels a compressed-air plant was installed, that at Eastview consisting of three electrically operated Ingersoll-Rand Air Compressors, Imperial Type X, two of capacity 1056 cubic feet; the other, 528 cubic feet of free air per minute. Six- and 5-inch lines supplied air to the portals and shaft. This pipe line had a length of 8400 feet. The current was supplied by the Westchester Lighting Company, at a voltage of 13,000, and was converted by transformers to 2200 volts, which was used in G. E. Co. three-phase induction motors to operate the compressors.

Central Crushing and Mixing Plants. A conspicuous feature of this contract was the large central crushing and mixing plant used for the cut-and-cover work, of a capacity of 36 cubic yards of concrete per hour. This plant was located at the intersection of the branch line to the Central Railroad and the contractor's line paralleling the aqueduct. Sand was brought to it in 6-yard side-dump cars loaded at the sand pit by a derrick operating 1-yard

Hayward clam-shell buckets. At the central mixer the sand was dumped through a chute to a large sand and stone bucket elevator which raised it to a high sand bin of 150 cubic yards capacity. Stone was brought to the plant from a quarry about 700 feet away in side-dump 1½-cubic-yard Koppel cars hauled up an incline to the level of the crusher by an electric hoist. The quarry was excavated with 2 to 4 Ingersoll-Rand, and 1 Sullivan drill and was blasted with 60 per cent forcite, the muck being placed in steel skips and lifted by a derrick onto the cars. A crusher (No. 5 Kennedy gyratory) discharged into the 80-foot bucket elevator above described. The elevator, in turn, discharged into a rotary screen at the top of the plant where the material fell into an appropriate bin of a capacity of 250 yards. Cement was delivered in car-load lots and unloaded into the cement shed alongside mixer, the capacity of the shed being 2000 barrels. From here it was elevated as needed by a cement bag elevator to the level of the mixing platform. Below the bin were measuring hoppers for sand and stone which discharged into a 1-yard Ransome mixer which in turn discharged into bottom-dumping Steubner buckets which were placed by a derrick onto flat cars and hauled to the site of the work, where they were unloaded by locomotive cranes. A mixing plant similar to above was also installed near the south end of the contract and a connected by a track with Putnam Railroad. Features making for considerable saving in transportation were the convenient connections to the main line of the Central Railroad, from which all materials were obtained, and the use of standard-gauge equipment over the whole work.

Excavation by Locomotive Crane Operating a Drag Scraper. For the earth excavation and open cut, an Interstate locomotive crane operating a 1½-cubic yard scraper was used. This machine moved in advance of the cut on 30-foot lengths of rail, which were moved ahead as fast as the machine advanced. As a rule, the scraper track was graded by hand before moving up the machine. The drag scraper deposited top soil on the uphill side, so that it could afterward be used to cover the embankment. The bulk of the excavation was spoiled in piles on the downhill side, being partly used for grading the service track. This grading was usually done by drag scrapers well in advance of other work. The material was rather hard to excavate by a drag scraper, as numerous boulders impeded its progress and prevented it shaping the cut to any well-defined lines, although as a whole the excavation was done nearly to the required slope. It was not allowed to work

PLATE 186.—Contract 52.—Excavation of Trench for Cut-and-cover Aqueduct with Locomotive Crane and Scraper Bucket.

closer than within ½ foot of subgrade, hence considerable hand trimming had to be done on sides and bottom just before concreting. Hand trimming of trench was economically done by piling the material in the trench and removing with locomotive crane and clam-shell bucket.

The above method has the great advantage of minimizing the handling of material, as it is deposited directly by the crane without the use of cars. Later on, the excavated material was recovered mostly by an orange-peel bucket, and by a clam-shell bucket operated by locomotive crane and then dumped over the aqueduct to form the completed embankment.

It is estimated that eight men worked on the excavation, averaging about 135 cubic yards per shift of eight hours.

Comparison of Drag Scraper with Steam Shovel. Excavation by drag scraper, as conducted on the contract, has the advantage that only one track is required for all operations, the machine operating on a temporary short length of track ahead of the trench, and piling material far enough to one side not to interfere with the single track alongside the trench; and subsequently, after concrete is placed, putting the excavation back, using orange-peel bucket. On Contracts 11 and 16 the steam shovels loaded directly into the cars, which required the use of an additional track laid on the uphill side and cutting in on the arch of the contract where a center track was used. This refill track was not continuous, however, and was taken up from time to time. In some cases on Contract 11 the shovels worked at night, filling cars operating on main concrete tracks. The writer is inclined to the belief that the expense of extra track laying of the steam-shovel method over drag-scraper method is more than repaid by the greater speed of both excavation and refill. A further comparison is made under Contract 53.

Excavation of Rock. In rock cuts four Ingersoll-Rand and one Sullivan drill, air driven, were used, the power being supplied by a pipe line from the main compressor plant. Blasted rock was spoiled at the sides of the cut by a 40-ton Interstate locomotive crane with 50-foot boom, operating an orange-peel bucket, the crane running on standard-gauge track alongside the trench. The rock was spoiled down hill from the track, as in the case of earth excavation, the intention being later to dredge it with orange-peel bucket to form main cover embankment.

Concreting of Cut-and-Cover. After the main portion of the trench was excavated by a drag scraper, as described, it was trimmed to sub-grade by hand, after which 15-foot sections of invert 16 inches thick were cast in alternate blocks, the concrete being hauled by an 18-ton dinky on a flat car holding eight buckets delivered from the central mixing plant and placed by a locomotive crane, which lifts the bottom-dumping 1¼-cubic yard Steubner buckets from the flat cars.

Construction of Invert. During 1910 the joints between the inverts were placed over key blocks 8″×8″ in section, as shown in the contract drawings. During the winter of 1910–11 tests on completed aqueducts showed that these joints were liable to leak. During 1911 the invert blocks were cast with squared ends in which were inserted steel plates 6 inches wide and of a length to join similar steel plate joints at the ends of arch blocks. These plates act as cut-offs to prevent water from escaping through these joints after they have opened through temperature changes. These plates were painted with asphalt paint. It was found that this not only gave a better joint, but one which saved considerable time in concreting invert over the old key-block joint.

After some length of invert was concreted, steel Blaw forms of the usual pattern were set up and 30- to 75-foot sections of arch cast complete in one operation, the concrete for this being furnished and placed as described for invert. Concreting was carried out simultaneously with the excavation, which was generally about 200 feet in advance of concrete invert and 500 feet in advance of the arch. On account of the greater speed of the concreting, usually accomplished in from one to two shifts, the excavation was often continued through two and often three shifts.

Eastview Tunnel. The Eastview tunnel is a grade tunnel of the usual design except that special provisions were made in the contract to pass about 1000 feet of a wet, sandy, boulder clay, filling the valley of a preglacial gorge. This depression might have been crossed by a siphon tunnel, as suggested by an alternate profile on contract drawing, but this seemed hardly worth while, as the stretch is so short. Provision was made in the contract for the use of compressed air, to pay for which special items were included.

Excavation in Bad Ground. The tunnel between portals is 5456 feet long, with a construction shaft 90 feet deep, 2000 feet from the south portal. In this shaft two balanced cages operated by a Lambert hoist were installed. The heading from the north portal was driven by the usual top heading and bench method for about 1900 feet, when bad rock and a great deal of water was encountered, causing a suspension of the work here. The tunnel from the south portal presented no unusual features. Northward from the shaft the tunnel was driven without special difficulty for about 350 feet, when a material containing hard clay, sand, boulders and wet seams was encountered. The timbering was begun with 12″×12″ timbering, five segments to the arch, placed 3 feet on centers. Wall plates in 20-foot lengths were placed in side drifts in advance of the heading proper. It was found that this timbering was giving way and intermediate ribs were placed with posts to support the cracked timbers. This, however, was not found sufficient, and the timbering was then placed 18 inches on centers and then skin to skin, but even this required the support of numerous cross-braces, the crown of the arch settling about 6 inches with some settlement of the ground overhead, indicating that the timbering carried the whole weight of the earth over the tunnel. The progress by this method was very slow, being only about 9 feet per week.

Use of Compressed Air. The contractor then asked for permission to use compressed air, which was granted November, 1910. A concrete bulkhead was built 260 feet north of the shaft and in it were placed a horizontal muck and man lock, and a 30-foot rail and timber lock. The excavation was continued, using air pressures from 9 to 25 pounds—average 20 pounds per square inch. The method of excavation and timbering was practically the same under the compressed air as in the open, but the progress was very much better, increasing from 9 to 25 feet per week.

The method of timbering was as follows:

Timbering in Compressed Air. Side drifts were driven ahead and in them 15-foot wall plates were placed. These drifts generally stood up, but were supported where necessary. In the next step the core was removed between the wall plates, to place the 5-foot segmental timbers, the tunnel being unsupported about 4 feet ahead of the timbers. The third step was the excavation of the bench and the setting of plumb posts between the wall plates. The trench for the plumb posts was excavated so that they could be set 4 feet in advance of the general bench excavation. The fourth step consisted of the placing of the invert timbering and interior bracing of the posts. When the solid rock dropped below grade sandy clay was encountered and solid invert timbering was placed, consisting of two 12″×12″ sticks sawed so as to give a drop of 9 inches toward the center to provide arch action. In addition there were two horizontal rows of 12″×12″ spreaders and numerous vertical posts.

PLATE 187.—Contract 52. Eastview Tunnel. Heavy Timbering in Compressed Air.

This type of construction was carried about 300 feet through the softest of the material, until a mass of disintegrated boulders was met and the bottom timbering discontinued. The timbering adopted

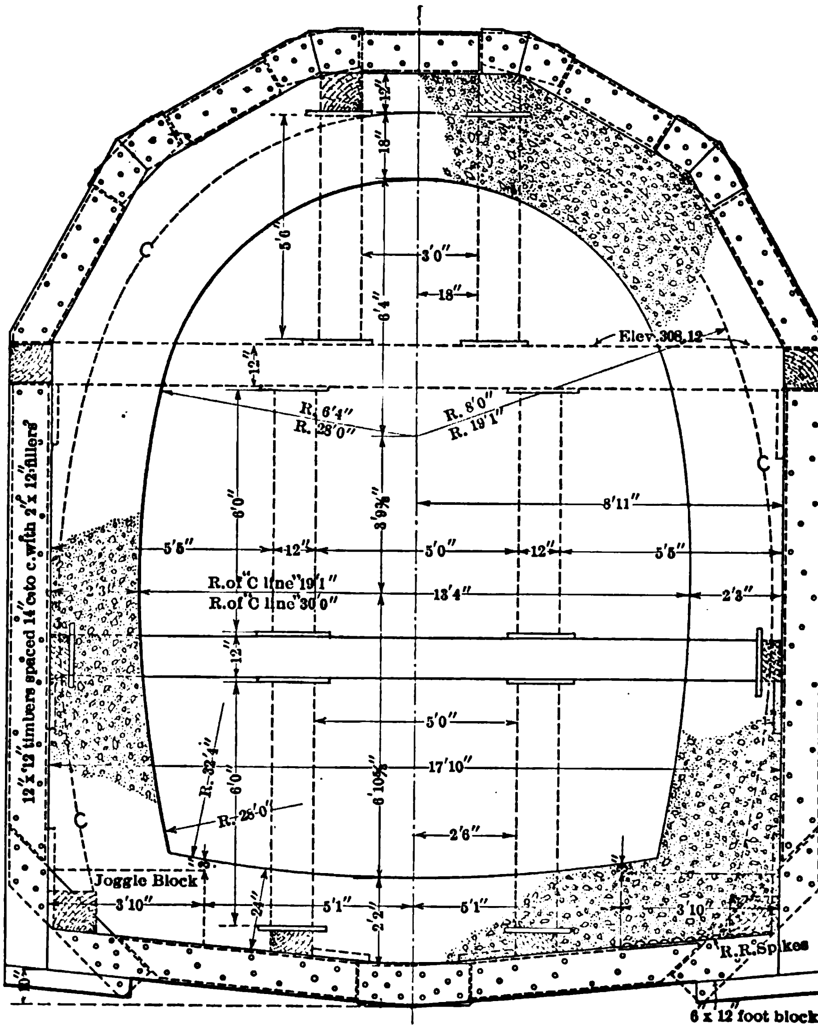


PLATE 188.—Eastview Tunnel Timbering in Heavy Ground and Concrete Lining. Used mostly for tunnel in compressed air,

is shown on Plate 188, and also on Plate 187. The arch timbers were set 12 inches high to allow for settlement, but it was found that the settlement was usually about 5 inches above the wall plates, this increasing very little with the placing of the plumb posts and inverts. An accidental demonstration of the pressure on the timbers of this tunnel was made at a time when the interior bracing lagged for about 100 feet behind the bench, due to the delay in timber delivery. At this time the compressor broke down for a period of three hours, the air pressure dropping to only 7 pounds. The 100-foot stretch became deformed, the wall plates forced out and twisted, and the segments settling so that the key block encroached about 6 inches on the concrete. As soon as this was discovered, interior bracing was placed and no further settlement occurred. In addition, this stretch was grouted with the use of a Caniff machine. A high-pressure line was used to force the grout from this machine, the mixture being 1 of cement and 2 of sand. Holes were bored through the timbers in about 15-foot intervals to take the grout pipes. It was found difficult to prevent leakage of grout between the timbers, but examination showed that the space back of the timbers was well filled with grout. Later a Cockburn-Barrow machine was used to place grout. When the arch concrete construction reached the depressed key blocks, the roof was chopped and the side walls moved out, so as to give an equivalent waterway and at the same time secure the required thickness of arch concrete. A large pipe was laid through the concrete, connecting the standard portions of the tunnel to prevent entrained air from reducing the waterway when under pressure.

Previous to the breaking through of the compressed-air heading to the tunnel excavated from the north portal an air lock was placed in a concrete bulkhead built in the completed lining of the open-air tunnel. The forms used for this part of the tunnel were thus locked in and used to line the stretch excavated in compressed air. It was not deemed advisable to remove the compressed air until after the concrete lining was placed.

Advantages of Compressed Air. The use of compressed air in this tunnel is considered to be of benefit both to the city and the contractor, and was the means of shortening what would otherwise have been a very long and tedious job. As is usually the case, the wet running ground held back by compressed air was dried out so that it could be readily handled. Considerable air escaped through the fissures in the rock, this being observed when the compressed-air heading was within 40 or 50 feet of the north heading. At one of the shafts of the new Croton Aqueduct not very far from this point soft ground was encountered, and several years were taken to drive a few hundred feet, the work, however, being

PLATE 189.—Eastview Tunnel Concrete Bulkhead, Material and Timber Locks for Compressed Air Section.

intermittent. Heavy timbering of the usual crown-bar and poling-board type was used here, the stretch finally being passed only after a great deal of settlement had occurred in the ground above. This place could probably have been readily excavated by the use of compressed air, but at that time compressed air for this purpose was comparatively little used. Nevertheless, there still remains on the part of many engineers and contractors a timidity in the use of compressed air, and much effort is wasted in driving through soft ground which could readily be saved by the use of air at moderate pressures.

Concreting Grade Tunnel. At the north end of the Eastview tunnel 93 feet of the usual type of Blaw tunnel forms were set up. These forms were mounted on carriages so that they could be moved in three sections. It is usually found that the concreting of tunnel lining progresses rather rapidly at first, when the side walls are being placed, but slows up materially when the keying-up of the arch begins. To save this delay and to keep the mixer working at a fairly uniform speed, Mr. Brink originated a method of concreting the whole 93-foot sections at one operation. A wooden bulkhead was built from the forms to the rock at each end and in the middle of the 93-foot section. The first concrete from the central plant, in side-dumping cars, was raised on a 90-foot I-beam incline to the platform 10 feet above the invert and placed in the side-wall section furthest from the portal. The concrete was carried up level on both sides to the point where keying up becomes necessary, the key concrete being started at the end and worked toward the center bulkhead. The surplus concrete was placed in the second section of the side wall, lower planks of the central bulkhead being removed to allow this concrete to joint up with the first side wall placed, which has had about twelve hours to set.

Keying up Arch. The central wooden bulkhead was taken down as fast as the concrete rose in the second side-wall section. By the time the inner half section was ready for keying the outer half section key was almost finished. The inner half key was filled, working from both ends toward its center, where four molded blocks were placed on top of steel form, giving an opening about 20 inches square, and the key concrete carried against these molded blocks, and the closure made by forcing concrete in this 20-inch opening through a special box operated by a piston. This metal box, fastened to the last key plate placed, was filled with concrete, and a piston operating in it was forced upward by a feed screw taken from an air drill.

Method of Moving Forms. Concrete cars, two cars at a time, were hauled from the mixer to the forms by an electric locomotive and up the incline to the platform by an electric hoist. The incline was a light steel structure resting on wooden bents. Before the entire key concreting of a 93-foot section was completed, 30 feet of the outer forms were unbolted ready to be moved ahead. The last of the forms are loosened up about fifteen hours after finishing the key closure. In the interval between finishing concrete and moving forms forward the regular gangs work ahead, cleaning and getting a section of the tunnel ready for concreting. It usually took five shifts of eight hours to concrete a 93-foot section, and an interval of another five shifts elapsed before the concreting of another section starts. Fifty men usually worked on the day shifts and 25 men on each of the night shifts.

Comparison of Eastview and Usual Method. The progress made by this method is not greater than by the method usually used, such as described under the Bonticou tunnel, but it has the advantage that one setting of the incline is necessary for 93 feet, and considerable time is probably saved by cleaning at only one point, and it is unnecessary to pull the concrete cars through the forms. There should be some economy in this method, as the concrete plant is kept at pretty nearly its full capacity, instead of at times very slowly, as when keying up is alone in progress under the ordinary method. The general principle is the same as that used in the siphon tunnels when side walls and arch are concreted at the same time by the use of trailing forms, as described under Rondout and Wallkill siphons. Comparison with the method of concreting used at Eastview tunnel and Peak tunnel, shows that the latter was probably more economical as greater progress (40 feet per day) was made with a smaller daily force, the bulk of the work being done in practically one shift, whereas three shifts were carried at Eastview. With the ordinary methods of working three shifts, as at Bull Hill tunnel, 340 feet has been made in one week as against about 210 feet at Eastview.

Concreting in Compressed Air. The concrete was mixed at the south portal plant, and hauled to the south bulkhead by electric trolley in cars small enough to go through the air lock. Within the compressed-air section, the cars were pushed by hand to the forms, where they were raised to the platform on an elevator built onto and moved with the forms. Two sets of forms, each 30 feet long, were used, one working from the south end and one from the north towards each other. The elevator in each case was on the forward end of the forms. The elevator was necessary on account of the large amount of internal bracing, which did not permit the use of the ordinary incline. Eight hundred feet of tunnel was concreted by this method between March 11, and May 24, 1912. The track carrying the concrete cars was laid on stringers blocked up so that the invert could be built in alternate sections under it. After the first sections had set, the blocking was shifted to them, and the remaining sections built. This invert concreting was kept as close as possible to the work on the arch. The compressed air was removed on June 4, 1912, and it was found that the tunnel showed very few leaks.

Rock Drills used in Eastview Tunnel. In the earthy portion of the Eastview tunnel the material had to be blasted, being too hard to be either picked or shoveled. This material was usually drilled by hand drills, churned in and out with water, it being found that the electric drills stuck in the holes. In rock, compressed-air drills were used, fifteen Ingersoll-Rand and two Sullivan. Four drills were mounted on two vertical columns, drilling the heading in the usual way. The bench was drilled by two machines mounted on tripods. The average progress made in the Eastview tunnel in rock, outside of compressed air, was about 200 feet per month. Considering the unususal difficulties to be overcome the progress made is very creditable to the contractor.

Electric Drills, Fort Wayne. This contract is distinguished from others by the use made of electric drills, of which three types were used, the Fort Wayne, the Dulles-Baldwin, and the Pneumelectric. The Fort Wayne drill operates a twist bit with chisel edge like an auger striking repeated blows as the bit is rotated. The motor is belt-connected to a device which drives a number of hammers by centrifugal force against the top of the drill steel. This drill worked fairly well in the soft material penetrated in the Eastview tunnel, under compressed air, but it was not successful for harder material. The drill was tried later by the same company on Contract 65 at the bottom of shafts in Manhattan schist, but it could make but slow progress in this moderately hard rock. It has been elsewhere used to advantage in drilling coal and soft shales.

Pneumelectric Drill. The Pneumelectric drill is operated by an electric motor compressing the air by means of a piston operating in the same cylinder as the hammer, which strikes a dolly which in turn strikes the hollow steel through which water is forced through a connection with the dolly. This machine was at a disadvantage at Elmsford owing to the lack of water under pressure.

Dulles-Baldwin Drill. The Dulles-Baldwin drill was the most successful under the conditions encountered on Contract 52. This seems to be the simplest type of electric drill and is the nearest approach to the ordinary reciprocating piston drill, using the same steel and bit attached to a piston connected directly to the chuck of the drill. An electric motor attached to the top of the drill operates a reciprocating piston which by means of suitable valves compresses air alternately on each side of the piston attached to the drill steel. Many minor improvements were made in this drill during the progress of this work by the manufacturer, but it was deemed expedient to carry a duplicate equipment of these drills to avoid delays.

Dulles-Baldwin in Elmsford Tunnel. The Dulles-Baldwin drill has been used in the Elmsford tunnel, where it was not given a good trial, owing to a wide fault with soft rock extending from 500 to 600 feet and necessitating timbering close to heading. Up to March, 1912, the average weekly progress in the tunnel was only 23 feet for the heading, maximum 53; for the bench 36 feet, maximum 70 feet. In driving the Elmsford tunnel after March 12, the heading was driven wide to accommodate timbering, but in excavating the bench below the wall plates considerable rock remained within the C line, and owing to the absence of an electric Jap drill there was no means for taking this out except by hand drilling or bull point, or by installing a traveling compressor to operate hammer drills. The Pittsburgh Contracting Company also used electric drills on Contract 65 of the City Aqueduct, and a more extended discussion of them is there given.

Contract 53

Contract Prices. Contract 53 was awarded to the Elmore & Hamilton Contracting Company, in December, 1909. The total contract price was $1,715,160.

Following the death of Mr. Elmore in June, 1911, this contract, as well as Contract 15, on the Wallkill Division, went into the hands of the receivers, Messrs. Sleden and Hand.

Some of the bid prices were as follows:

Open-cut excavation, cubic yards	$0.45 to 1.00
Refilling and embanking, cubic yards	0.25 to 0.50
Concrete masonry in open cut, cubic yards	5.25
Portland cement, barrels	1.60

Estimated cost of cut-and-cover from contract quantities is $60 per foot.

Work and Location. This contract includes the most southerly stretch of cut-and-cover on the Catskill Aqueduct, and comprises about 4.6 miles of cut-and-cover and a short reinforced concrete siphon. The work lies about 2 miles back of the Hudson River, near Hastings and Dobbs Ferry.

Methods and Plant. Methods and plant similar to that of Contract 15 were used on this contract, and but for the interruption due to the change of management very good progress was made.

The cut for the aqueduct was made by two 60-ton Marion shovels equipped with long booms (30 feet) and 1-yard buckets. These shovels deposited the spoil on a long storage pile west of the aqueduct. On this pile a track with three rails for both standard and narrow-gauge cars was laid, to permit the operation of locomotive cranes and narrow-gauge equipment. The shovels also loaded into cars which were dumped over the aqueduct for refill and embankment. Over part of the line the earth cover was 5 to 6 feet in depth. The rock was exposed in three pits dug on transverse lines at the aqueduct, and about 9 feet apart. In these pits drills were set up, holes drilled and the rock and overlying earth blasted together. A steam shovel rigged on a derrick was moved along the bottom of the trench, and used to remove final hand excavation.

Quarry. A quarry in gneiss rock was opened and equipped with crushing plant composed of one No. 6 and one No. 3 Kennedy crusher with bins to hold crushed product. One 150 H.P. boiler and 60 H.P. engine operated the plant.

Concrete Plant. The concrete plant was served by a derrick with clam-shell buckets which moved sand and stone from storage piles (made by wagons) to the bins over a Smith mixer, which discharged into bottom-dump buckets hauled on flat cars by dinkies to the work, where the buckets were placed over steel Blaw forms by locomotive cranes. A cement shed near the mixer held 1000 barrels of cement. The cement was raised to the mixer platform by the derrick described. The concrete plant and outfit described was easily capable of concreting 60 feet of aqueduct in eight hours.

Steam Shovel Records. On this contract a careful record was kept by the engineers of the performance of the steam shovels. In earth, the shovels removed from 300 to 830 cubic yards per eight-hour shift. In 90 per cent rock (disintegrated schist) 100 to 500 cubic yards were removed per shift, and in rock 50 per cent partly disintegrated schist, 250 to 550 cubic yards were removed.

One shovel in all materials averaged 354 cubic yards per eight-hour shift, the other 366 cubic yards in the same time. Although these records are much below the usual performance of a 60-ton shovel under favorable conditions, when account is taken of the narrow trenches and variable materials in which the shovels worked, the work was very good.

Advantages of Steam Shovels as Compared to Other Excavating Tools. Off-hand, it would appear that to use a machine under conditions which compel it to work far below its average speed, would not pay. Nevertheless, experience shows that while the steam shovel cannot, in aqueduct trenches of the size and shape required for the Catskill cut-and-cover aqueduct, do its best work, it still is capable of doing much more and better work than any other excavating tool used, as shown by careful records kept of the performance of the locomotive crane with a 75-foot boom and drag buckets, operated on the neighboring Contract 52. The performance of this machine was only 136 cubic yards per shift of eight hours excavating in earth, ranging per shift from 70 to 240 yards. This is only about one-third the performance of the steam shovel. The steam shovel is a perfected tool of wonderful reliability, it being very seldom necessary to stop it for repairs or because of breaking down. As shown by the records, the locomotive crane during the season of 1910 was laid up for repairs for considerable periods. The shovel has the great advantage of being able, when operating in deep cuts, to dig at a high rate and get out of the way of concrete or other operations. For the same reason, it can take advantage of favorable weather conditions, and so does not suffer so much from bad weather. The steam shovel can also dig much closer to line and grade than any other machine excavator, and with its powerful arm is capable of removing boulders, stumps, and other obstructions which impede its path.

CHAPTER XVIII

YONKERS PRESSURE TUNNEL AND HILL VIEW RESERVOIR

CONTRACT 54

Work and Prices. This contract, located just north of the Hill-view reservoir, comprises all of the Yonkers pressure tunnel except 1200 feet adjacent to the uptake shaft included in Contract 30. It was let early in 1910 to Geo. W. Jackson, Inc., of Chicago. It is 11,149 feet (2.1 miles) long, finished diameter 16 feet 7 inches. It is constructed from three shafts and a triple portal at the northern end. The shafts are 154, 106 and 116 feet in depth. The total contract price is $1,479,425, which is moderate for a tunnel of this size and length. Some of the prices are as follows:

Construction shaft in rock, per foot	$210.00
Refilling construction shaft, per foot	40.00
Excavation of tunnels, cubic yards	4.75
Concrete masonry in shaft and tunnels, cubic yards	4.80
Cement, barrels	1.55

Based on contract quantities the estimated cost of pressure tunnel, including valves and chamber, is $126 per foot, of construction shaft in rock, $253 per foot.

This work, after being in operation one year, was taken over by a creditors' committee, although Mr. Jackson continued in charge of the work for the committee.

Power Plant. A central power plant was installed electrically operated by a 6600-volt A.C. current, transformed down to 440 volts to operate the motors for the five air compressors, as follows:

1 Ingersoll-Sergeant	800 cu.ft. per minute
1 Ingersoll-Rand	1200 " "
3 2-stage Ingersoll-Rand	2000 " "

All these compressors were belt-driven and housed in one wooden building. In an adjacent concrete building were housed the switchboards and transformers. From this plant, situated at

Shaft 2, 8- and 6-inch pipe lines ran to the other shafts and to the portals, 4-inch lines carrying the air into the portals.

Sinking of Shafts. All three shafts were sunk in dry rock, Shafts 2 and 3 requiring a little pumping, maximum amount pumped per shaft being 70 gallons per minute. To reduce surface leakage and provide foundation for head frames the upper portions of Shafts 3 and 2 were concreted down to 35 feet. At Shaft 1 the head frame was founded directly on the rock surface at the top of the shaft, this shaft being extremely dry, yielding practically no water. Stiff-legged derricks were used to excavate the shafts, which were excavated to subgrade in about four months with the contractors' organization. Until the compressor plant was put into operation power was furnished to the drills from portable 40 H.P. boilers.

Shaft Equipment. Shafts are rectangular and were equipped with two balanced Otis cages operating in two compartments; the third compartment is used for ladders and pipeways. The cages were suspended from double cables equipped with flyball-operated safety clutches. This device was operated by a hemp rope which ran over wheels on the cage and extended down the depth of the shaft. At the bottom of the rope a heavy weight was permanently attached. In case the cable breaks and the cage drops too fast, the wheels of the governor rotate to force a wedge against each of the steel shaft guides. This device is not considered as reliable as the toothed cams operated against wooden guides, such as is ordinarily used. The cages are operated by Otis single drum hoist, using compressed air from the central power house.

Tunnel Excavation. In general the headings were carried through between shafts and portals before starting work on the bench as the only ventilation of these tunnels was that due to the operation of drills and the liberation of air from the 4-inch high-air lines at the headings. Some parts of the tunnels were very smoky throughout most of the day previously to the meeting of headings. The method of excavation varied from time to time, owing largely to the frequent changing of superintendents on the ground. Usually the full top heading was taken out to about 1 foot above springing line, though for some distance a narrow 9×12-foot heading was excavated. At first an endeavor was made to pull 10-foot cuts in the headings, working three drilling and three mucking shifts, the drill holes varying in number from 26 to 32 for the full heading. This method often required reloading of the cut holes as much as three times before pulling to the full depth, so that it was impossible to make regular scheduled progress, and it was therefore abandoned.

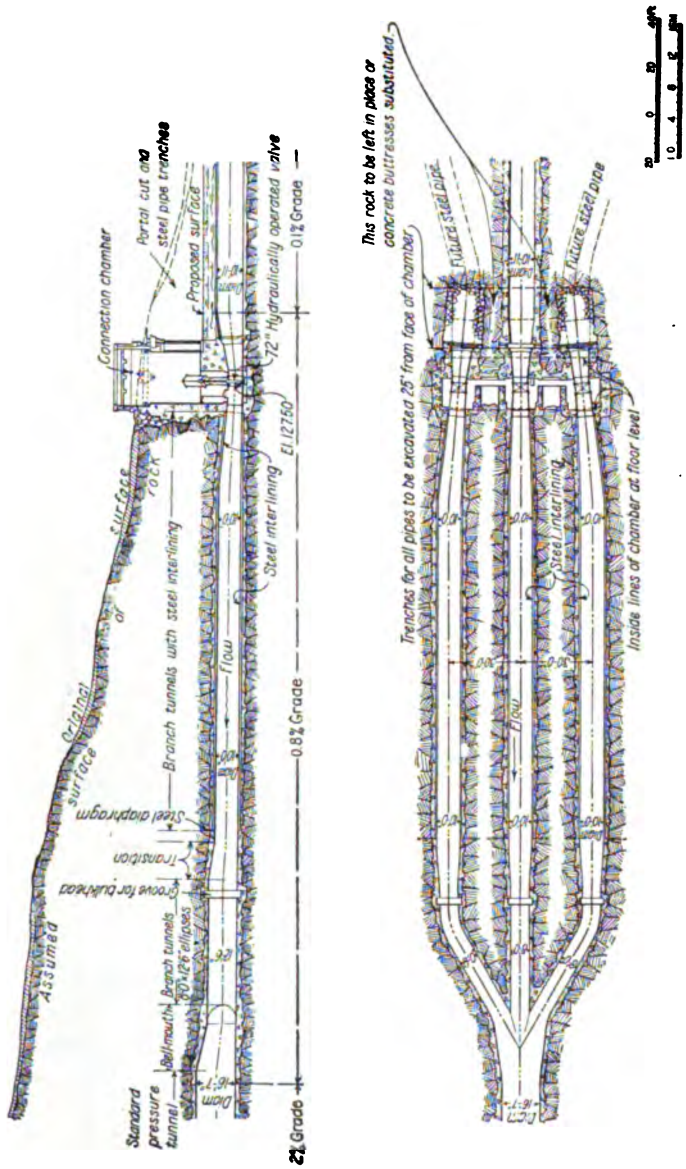


PLATE 190.—Triple Portal at Junction of Yonkers Pressure Tunnel and Bryn Mawr Siphon. Details of Construction.

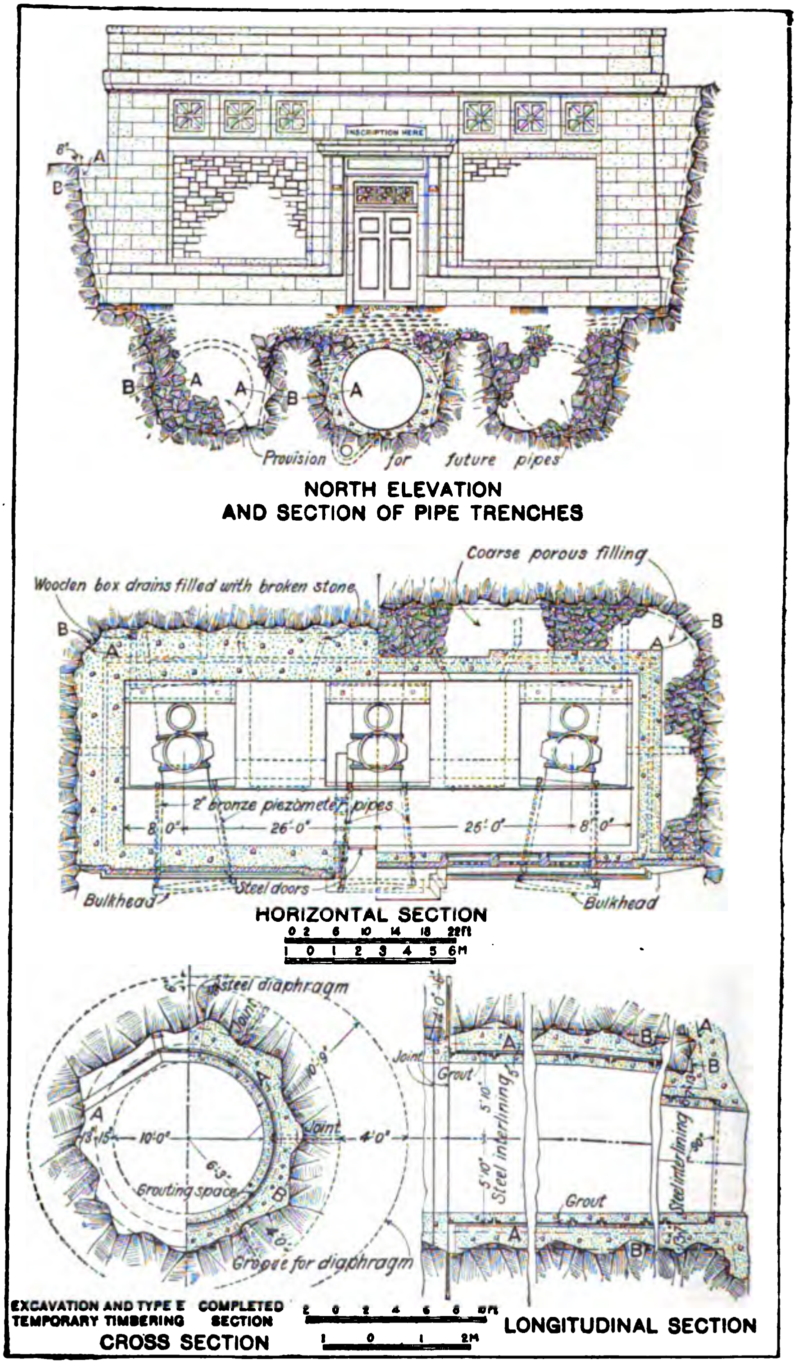


PLATE 191.—Junction Chamber of Yonkers Pressure Tunnel and Bryn Mawr Steel Pipe Siphon. Shows method of concreting pipes in tunnel.

This mistake is commonly made in tunnels driven with too long holes. It is better to make regular daily progress, using a depth of cut practicable to blast to nearly full depth with one loading.

Another Method of Tunneling. The second method was to cut down the advance to only 5 feet; 6 to 8 cut holes were drilled, 4 to 6 relievers, 6 bottom side and 3 top-dry holes, a total from 19 to 23 holes, requiring the use of 150 pounds of 60 per cent dynamite. The drill steel used varied from $2\frac{3}{4}$ to $1\frac{3}{4}$ inches. The heading was drilled and blasted in each of two drilling shifts, the three rounds of holes being fired separately. At each drilling shift, 4 drillers and 4 helpers and a foreman were engaged. With each drilling shift a mucking gang of 1 foreman and 8 to 12 muckers worked from 12 P.M. to 8 A.M., and from 12 noon to 8 P.M. In addition, a split mucking shift of picked men worked from 8 A.M. to noon, and from 8 P.M. to 12 P.M., in an endeavor to clear the headings, to allow the setting up of the two columns with their two drills.

Bonus System, etc. The work was partly done under a bonus system based on the daily or weekly progress, and the yards per foot excavated. A disadvantage of the bonus system is that although it tends to rapid driving, it is apt to lead to a rather poorly driven tunnel. The general superintendent of the Rondout siphon after consulting the cross-sections obtained by the engineers succeeded in discouraging poor driving by liberally discounting the poorer tunneling, so that on the whole the tunnels were well driven. The bench was excavated by working four drills, two on tripods and two on columns. The column drills were used for trimming headings, which in many places were driven rather narrow. The drilling shift worked from 8.30 to 4.30 P.M. blasting the bench between 3 and 4.30. Two shifts of 12 muckers worked from 12 P.M. to 8 A.M. and 8 A.M. to 4 P.M. Throughout all the excavation Ingersoll-Rand $3\frac{5}{8}$ inch F94 drills were used. The rock excavated was very hard Yonkers and Fordham gneiss, requiring no timbering.

Mucking Machine. An effort was made in one tunnel heading to use a mucking machine patented by Mr. Jackson. After a few weeks it was abandoned, but was later used on the spoil bank. The machine was mounted on a truck having broad wheels and moved by its own power on a board platform and operated a series of buckets on an endless inclined chain, the buckets digging into the muck and dumping the same onto a belt conveyor which loaded the cars. The machine was used for loading the tunnel muck from the spoil bank onto 2-yard cars which were hauled to the crusher and

PLATE 192.—Yonkers Siphon. Triple Portal of Tunnel at Junction of Bryn Mawr Steel Pipe Siphon. Pipes will run about 100 ft. into tunnel and are to be concreted in.

was operated by an engineman and a helper whose duty was mostly to free the machine from being jammed by the large stones of the spoil bank. It was operated by compressed air, its claimed capacity being about 50 cubic yards per day. Four machines were delivered but only one was tried in the tunnel.

Concreting Methods. The concreting plants, method and forms used at the Yonkers tunnel, Contract 54, were entirely different from those employed at any other similar work on the aqueduct, and therefore will be described in some detail.

At each shaft there was a stone-crushing plant consisting of a No. 6 McCully gyratory crusher with conveyor, screens and elevated bins. From Shaft 1 to the portal at the north end an aerial tramway 3000 feet in length was operated by a 25 H.P. motor and equipped with buckets of $\frac{1}{3}$-yard capacity. The cableway was used for the transportation of concrete material between these two points.

All the concrete plants in use were gravity mixers of the Hains-Weaver type, containing four superimposed hoppers of 17 cubic feet capacity. At the portal one of these plants was located in the cut near the East tunnel entrance; at Shaft 1 the mixers were situated at the foot of the shaft just under the tunnel roof, the clearance below the bottom hoppers being sufficient to permit 1-yard cars to run beneath and receive the concrete. The aggregates were measured in wooden tilting hoppers at the top of the shaft and discharged into chutes of 15-inch spiral riveted pipes leading to the mixer hoppers. The cement was carried in bags on the cages to the working platform directly under the tunnel roof and there put into the hoppers by hand. The portal plant was charged with materials from overhead bins in the usual manner.

Operations of the Hains Mixers. The mixers as used here were not entirely satisfactory. The tunnel afforded too small a height for the proper placing of the four Hains hoppers and consequently the concrete was not mixed nearly as well as when the full drop from bucket to bucket is obtained, as in the full-sized Hains plant mounted in towers. The sand and stone frequently clogged in the 15-inch pipe, causing considerable delay until the pipe could be freed by long poles. Here, as elsewhere, it was found difficult to send damp materials through pipes, either excessive wear or clogging resulting.

The mixer plant at the portal was arranged so that one man could open all the pockets from the top, saving the men who usually operate the door at each platform level. This device was tried out also on Contract 11, and with the same experience as here. The top man found it hard to operate the doors at the proper time, so that the batch was apt to drop through without being caught in each bucket, and the concrete, for this reason, was delivered in a poorly mixed condition, which often required remixing at the forms.

Invert. At first 90 feet of invert was laid to the width of 9 feet, but experience proved this to be too wide, and the width was reduced to 7 feet, the finished diameter of the tunnel being 16 feet 7 inches, as against $14\frac{1}{2}$ feet where 5-foot inverts were usually used. The invert forms were made of continuous side planks $3'' \times 16''$ set radially and supported from $6'' \times 8''$ timbers braced across the tunnel at 9-foot intervals about $2\frac{1}{2}$ feet above the invert grade.

Geo. W. Jackson Forms for Side Walls and Arch. For side walls and arch the Geo. W. Jackson forms were used. These forms differ from the usual Blaw forms used on other siphons, in that they are not provided with carriages and are intended to be moved piece by piece. They consisted of complete circular ribs of the diameter of the tunnel made of 5-inch steel I-beams, or of two 5-inch channels riveted together back to back and of $\frac{1}{8}$-inch steel lagging plates $1' \times 3'$, stiffened by $1\frac{1}{2}'' \times 1\frac{1}{2}''$ steel angles. The ribs were placed 3 feet apart and the lagging put on as the concrete rose. These forms contained no heavy pieces. About 90 linear feet of forms were provided at each working point. As fast as the concreting proceeded the forms were taken down at the rear, carried through and set up in advance, this all being done by hand. The forms afford good facilities for spading the concrete, as the plates are continuously added, but the small size of the lagging units give many joints to be finished off. Side walls and arch were brought up separately, the side walls being placed ahead of the arch. The concrete was hauled to the working platform at springing line up an incline by a hoisting engine at forward end of the platform, after which the cars were pushed by hand to the point where they were dumped. While concreting was in progress trimming and excavation of the bench was also carried on, and the muck hauled through the forms to the shaft. This was done probably because the headings had been driven through much before the benches were excavated and the contractor did not care to wait until the tunnel was entirely excavated before beginning concreting. The experience on other siphons is that it is better and more economical to finish all the excavation before attempting to concrete, as it has been found that the two operations conflict with each other. The progress made with Jackson forms was much slower than that made with forms equipped with carriages, as the latter forms can be moved and set up much quicker. The average progress made per day at one set of forms was about 14 feet, with two eight-hour shifts of concreters and a third shift of form setters. As previously described, on the Wallkill and other siphons, a daily progress of from 40 to 60 feet was readily made with another type of form.

CONTRACT 30. HILL VIEW RESERVOIR AND PRESSURE TUNNELS

Contract Prices and Work Included. This contract was awarded in December, 1909, to the Millard Construction Company; later the board approved the change of firm name to the Keystone State Construction Company. This contract includes the construction of Hill View reservoir and 1184 feet of the Yonkers pressure tunnel, an uptake shaft 141 feet deep connecting this pressure tunnel with the reservoir, a downtake shaft 304 feet deep at the other end of the reservoir leading into the city aqueduct tunnel (Van Cortlandt pressure tunnel), and 1809 feet of this tunnel. The total contract price of this work was $3,270,000. Some of the quantities and prices are as follows:

2,900,000 yds. excavation at........	$0.28 cu.yd.
2,750,000 yds. embankment at......	.20 impervious refill; 10 cts. other refill
4,700 cu.yds. of shaft excavation at..	16.00 per cu.yd.
39,500 yds. tunnel excavation at.....	6.20 per cu.yd.
135,000 yds. concrete in open cut	4.70 cu.yd.
60,000 cu.yds. reservoir lining	
75,000 cu.yds., walls, chambers, etc.	
Forms for lining tunnel............	3.00 lin.ft.
14,400 yds. concrete in tunnel.......	6.00 cu.yd.
215,000 bbls. Portland cement	1.60 per bbl.

Cost of pressure tunnel based upon contract quantities is about $142 per foot, of waterway shaft about $303 per foot.

Hill View Reservoir. Hill View reservoir will contain 900 million gallons and its purpose is to equalize the difference between the consumption of water in the city and the steady flow of the aqueduct, particularly in times of fire. Were it not for this reservoir the Yonkers pressure tunnel and the city aqueduct would be directly connected. As it is, there is a space of about 2500 feet between the Uptake shaft of the Yonkers tunnel and the Downtake shaft of the City aqueduct. These two shafts are situated within the reservoir embankments and are connected across the Hill View reservoir by a circular by-pass aqueduct, 12 feet in diameter under

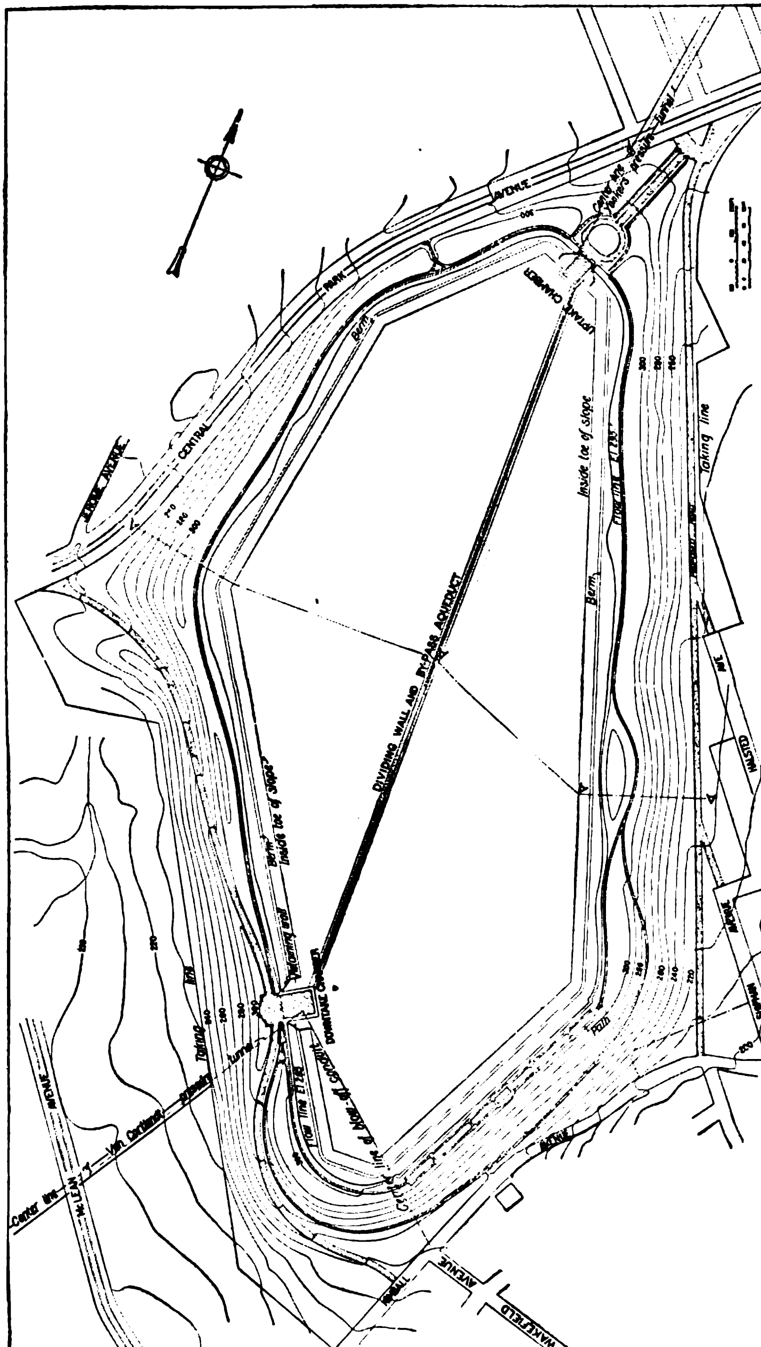


PLATE 193.—Hill View Reservoir. Contour Plan Showing Uptake and Downtake Shafts and Adjoining Yonkers and City Aqueduct Pressure Tunnels. Also By-pass Aqueduct in Dividing Weir.

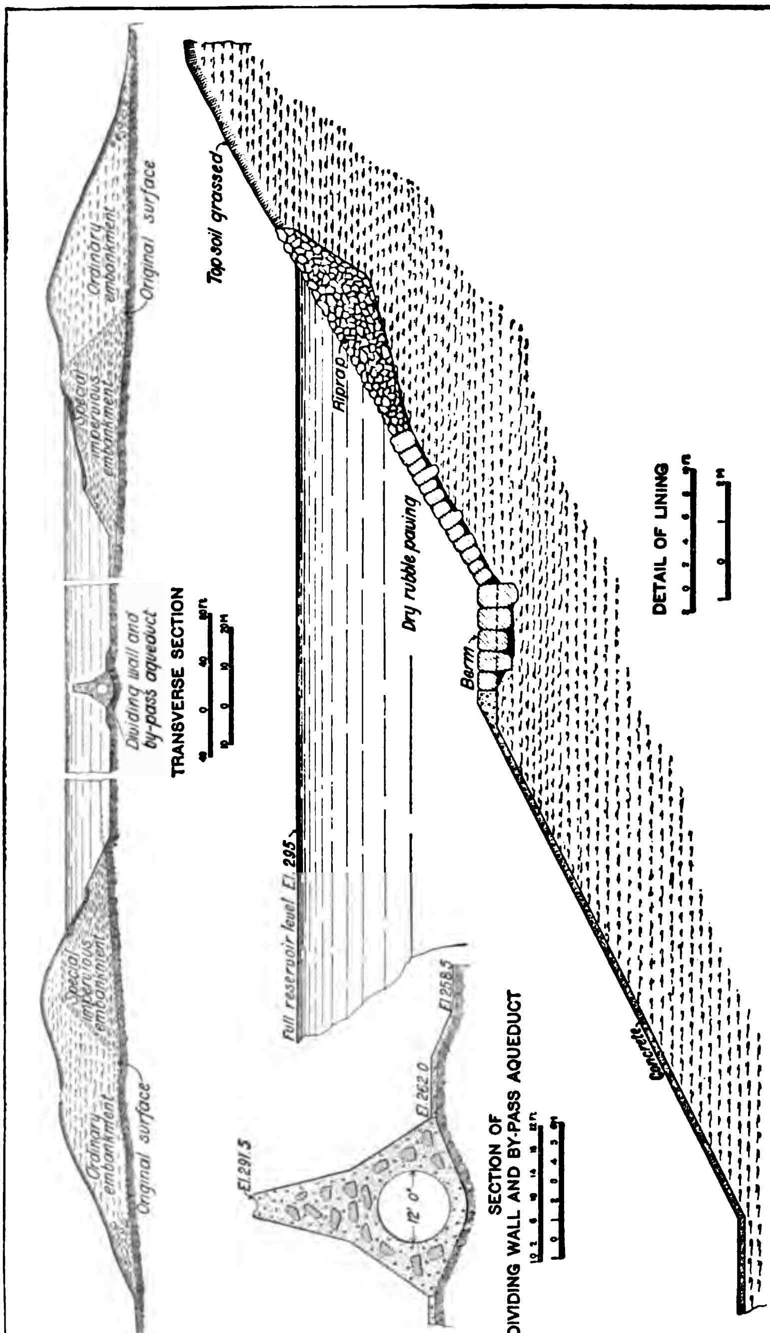


PLATE 194.—Embankment and By-pass Aqueduct of Hill View Reservoir. Details of Construction.

a 24-foot head at its crown, in the heavy concrete dividing wall of the reservoir. This reservoir occupies an area of about 90 acres on both sides of the dividing wall, and will when full cover the top of wall with 3½ feet of water. It is entirely artificial being excavated at the top of a large glacial hill. It was a most fortunate circumstance to find a hill so near the city line, largely unoccupied and obtained at a price comparatively small. It is composed entirely of boulder till or unmodified glacial drift. The central portion of the reservoir was excavated to a depth of 20 to 45 feet, the material so excavated being used for surrounding earth embankments, a portion of which is composed of carefully rolled layers, 4 inches thick, the remainder on the outside being deposited in 2-foot layers without rolling.

Soil Stripping. The reservoir site was well wooded. The trees were cut up into railroad ties and lumber by the contractor's saw mill. The future embankments will be grassed and require the use of a large quantity of topsoil. This topsoil was carefully removed and with considerable difficulty, on account of the large number of stumps and boulders. The soil was loosened with mattocks, excavated with hand shovels, and transported to storage piles on wagons or cars. Two-foot-gauge cars were run on an industrial track, which was laid on a down grade so that the loaded train traveled nearly the entire distance to the spoil bank by gravity. The empty cars were hauled back by horses. In this manner 133 acres were stripped—212,800 cubic yards.

Main Excavation. The excavation and embankment work were such that steam shovels could be used under almost ideal conditions. Although the glacial drift with numerous boulders could readily be dug by the shovels, it was still stiff enough to stand on almost vertical slopes even through the winter. To loosen up the material holes were put down by well or churn drills. These were sprung and blasted in the usual manner. The first excavation was made by steam shovels near the uptake and downtake shafts, where an area of three acres was excavated to reservoir grade to make room for a crushing and concrete plant and storage room for materials. These excavations were connected by a cut along the location of the dividing wall. This made room for the starting of the two shafts and for the subsequent building of the dividing wall, besides giving good faces for the steam shovels. The shovels were as follows: Two 70-ton Bucyrus, one 60-ton Marion, one 65-ton Bucyrus, and four 30-ton Ohio. Three of the larger shovels mentioned were served by 4-yard Western dump cars, hauled by

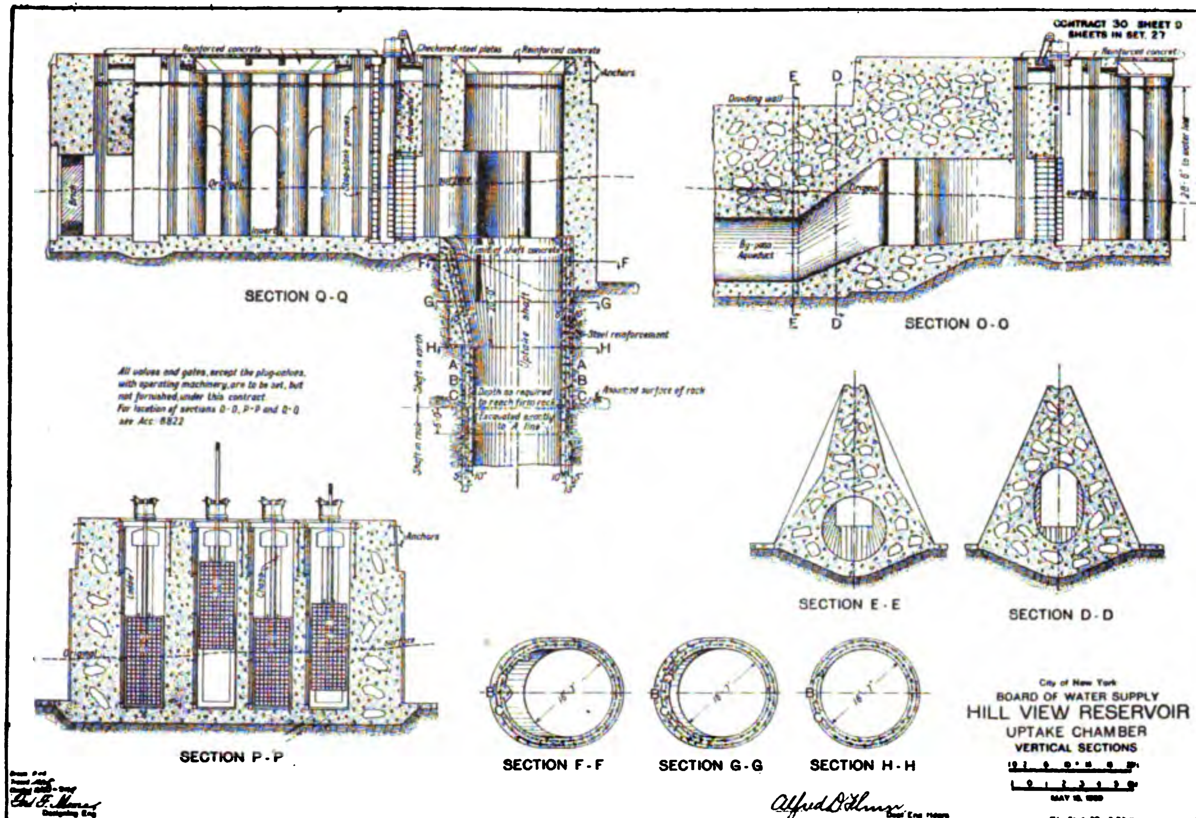


Plate 195.—Hill View Reservoir. Details of Uptake Chamber. Yonkers Pressure Tunnel Discharges into the Reservoir through this Chamber. Beginning of By-pass Aqueduct.

Plate 196.—Hill View Reservoir. Spreader Used for Reducing Material Dumped from Cars to Proper Thickness for Rolling by Steam Roller to Make Impervious Embankment.

locomotives on tracks of 3-foot gauge, and their contents deposited in the embankments. After this material was dumped, it was leveled off by a special leveling car which operates in a manner similar to the ordinary road scraper, but is pushed by a locomotive.

Impervious Embankment Construction. The inside portion of the embankment is formed of selected material spread in 5-inch horizontal layers which when rolled are not more than 4 inches thick. Great care was given to the preparation of the base of this embankment, all soil, loose boulders, stumps and roots being removed, and the ground was roughened with a plow and sprinkled before placing the first layer. When wagons were used the earth was dumped in rows spread to the required thickness by four-horse road scrapers and rolled by 10-ton Buffalo grooved steam rollers. The material as it came from the excavation contained enough moisture to compact properly, but during hot weather the embankment required sprinkling before a fresh layer was spread. The base of the 2-foot embankment was prepared by removing topsoil, stumps and nests of boulders.

Excavation 1911 to 1912. During 1911 one 65-ton and one 70-ton Bucyrus shovel were added to the equipment and the daily capacity for excavation increased to 5500 cubic yards. Three of the heavy shovels were served by trains of 4-cubic-yard Western dump cars, one by wagon, three small shovels by wagons alone, and a fourth by wagons and train. There were eight shovels working at one time mostly in the west basin. Drilling and loosening the deep portions of the excavation with powder ahead of the shovel was the common practice. The reservoir was gradually excavated from the sides of the two basins toward the center, the shovels working to a few feet above the bottom. At the close of 1912 219,000 cubic yards of topsoil and 2,160,000 cubic yards of main excavation had been removed, all of the latter being used for 4-inch embankment (846,000 cubic yards) or for refilling and embankment (mostly 2 foot layers) of other classes.

Making Embankments 1911. As at the Ashokan dam (Contract 3) it was found that embankment could be most expeditiously and satisfactorily made by train. A double line of 3-foot-gauge track was installed on the east and west embankments. After dumping the trains of 4-yard side-dump cars along the full length of a track, the spreader car was twice run along the track, spreading the material. The track was then moved back 13½ feet by horses, and spreading and leveling for the 4-inch layers completed by a

PLATE 197.—Hill View Reservoir. Spreading, Sprinkling, and Rolling of Embankment Forming Rim of Reservoir.

four-horse road scraper after which the 10-ton grooved roller completed the operation.

Removing Boulders. A great many boulders were rejected by the steam shovel, but many reached the embankments, where they were separated by hand during dumping and spreading, loaded on wagons and hauled to crushers. As it was necessary to remove the stones promptly a large number of men were required for this purpose. A very convenient rig for breaking up boulders consisted of a gasolene-operated compressor which furnished air to jap drills. A few holes and plug and feathering sufficed to break the boulders into blocks almost ideal for the heavy 18-inch pavement which will be used in great quantities adjacent to the water line of the reservoir. The material for the outside embankment in 2-foot layers was mostly hauled in trains, but it proved impracticable to save the boulders from the material. A considerable amount of excavation for both classes of embankment continued to be hauled in wagons.

Plant Used for Excavation and Embankment. The plant for excavation and embankment, besides the 8 steam shovels mentioned, Bucyrus, Marion and Ohio, included 16 3-foot gauge locomotives (Porter, Baldwin, Davenport and Dixon, makers) 19,200 feet of narrow-gauge tracks, 90 Western dump cars, 5 road scrapers (Western and Champion), 3 Buffalo-Pitts 10-ton grooved steam rollers, 112 Troy dump wagons, 6 sprinkler wagons (Austin and Studebaker), 2 Western levelers, etc.

Shaft Plants. The two shafts and adjacent tunnels were superintended by the Dravo Contracting Company, who did all the work of excavating and lining shafts and tunnel. Independent air-compressing plants were erected at each shaft. At the uptake three horizontal fire-tube boilers, combined capacity 280 H.P., two Ingersoll-Sergeant single-stage air compressors operated by steam and rated at 1100 cubic feet free air per minute, also a direct-current dynamo operated by a 30 H.P. Erie engine. At the downtake shaft the plant was very similar except that one compressor was two stage and rated at 1300 cubic feet of free air per minute.

Shaft Excavation. The shafts were sunk by means of stiff-legged derrick operated by Lidgerwood double-drum engine. The uptake shaft was sunk through 50 feet of earth and 22 feet of disintegrated rock which required timbering. Below this the rock was sound Yonkers gneiss or granite, and required no timbering, the total depth of the shaft being 143 feet. The average progress made in sinking was 38 feet a month, maximum 67 feet. The down-

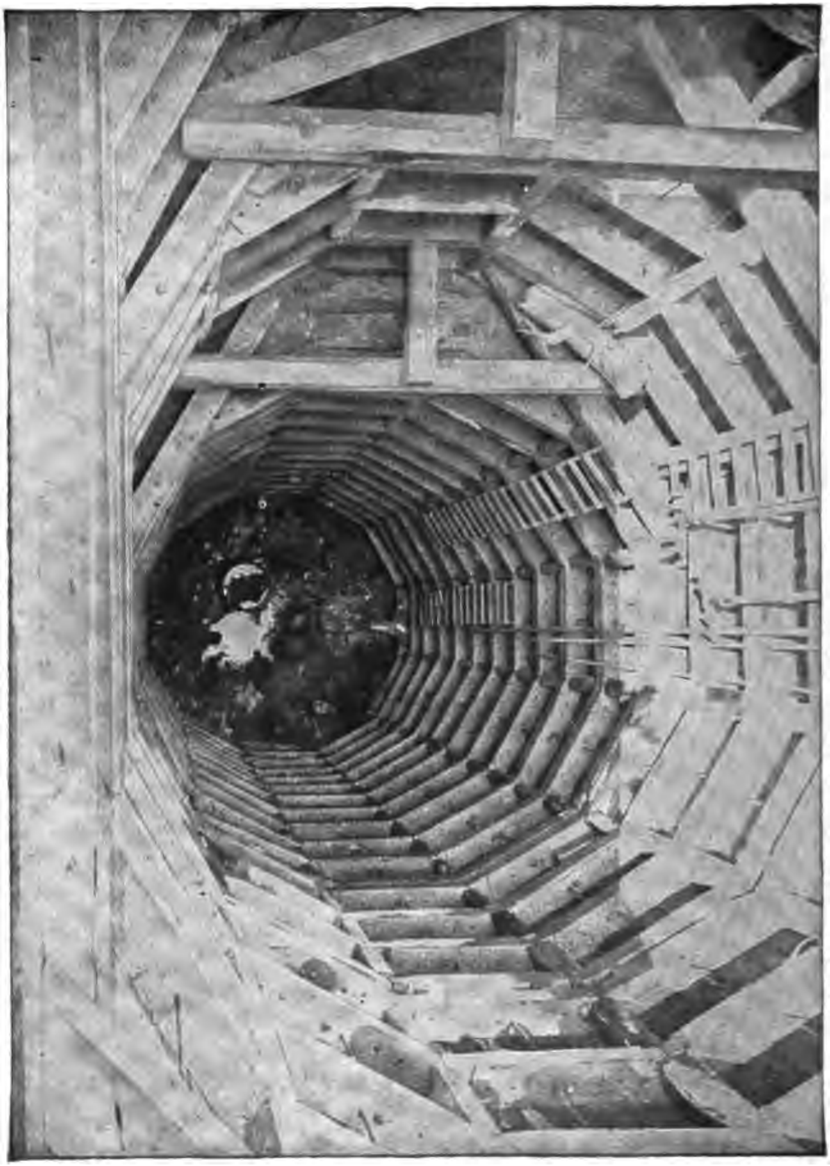


PLATE 198.—Hill View Reservoir. Timbering of Earth Portion of Downtake Shaft.

take shaft was carried through 67 feet of earth requiring timbering; the remaining distance, 244 feet, was sunk through solid Yonkers gneiss to tunnel grade, requiring no timbering. This shaft made an average progress of about 75 feet per month, maximum 96 feet. Yonkers gneiss is a very solid rock which most people would class as a pink granite. It is very hard to drill and no great progress can be made in it either with shaft or tunnel, but it is usually sound and often carries considerable water in narrow seams which bothers the excavation little, but is very troublesome during concreting.

Tunnel and Crushing Plant. The shafts were lined in the usual manner, using steel forms designed and constructed by the Dravo Company. At the downtake shaft 200 feet of lining in one month was placed. After the shafts were concreted, structural head frames 60 feet high were erected. These were composed of four temporary shaft-sinking head frames bolted together and strengthened by timber braces. In them were operated two balanced Connellsville self-dumping shaft cages, worked by a Vulcan mine hoist with 66-inch drum. A special low steel muck car was designed and built for the Dravo Company. This car sat very low on the frame and was equipped with a front door, the arrangement being such that when the cage reached the top of the head frame its floor was tilted by wheels entering a curved trackway, the floor of the cage being mounted on shafts. The car was held fast while the front door was automatically opened and the muck deposited in a high timber bin, from which it was run into a crusher and through a screen, the screen feeding onto a long belt conveyor, supported on high trestles so as to dump the crushed rock into a high conical storage pile. All the rock of the tunnel was directly crushed up in this manner to stone grading up to about 2 inches in size. The fine screening or stone dust made excellent sand which was used in the concrete as a substitute for natural sand, which in this neighborhood is very scarce. The stone-crushing arrangement above mentioned was most excellent, as it economically disposed of the tunnel muck by converting 100 per cent of it into materials used in the concrete. Yonkers gneiss gives little trouble in the crushers and screens, contrary to the experience with most tunnel muck, which is very apt to be wet and sticky, clogging the crushers and screens, so that the resultant product is a varying mixture of broken stone and fine crusher dust.

Bottom Heading. A feature in driving the tunnel was the use of the bottom heading method. After a short distance had been driven

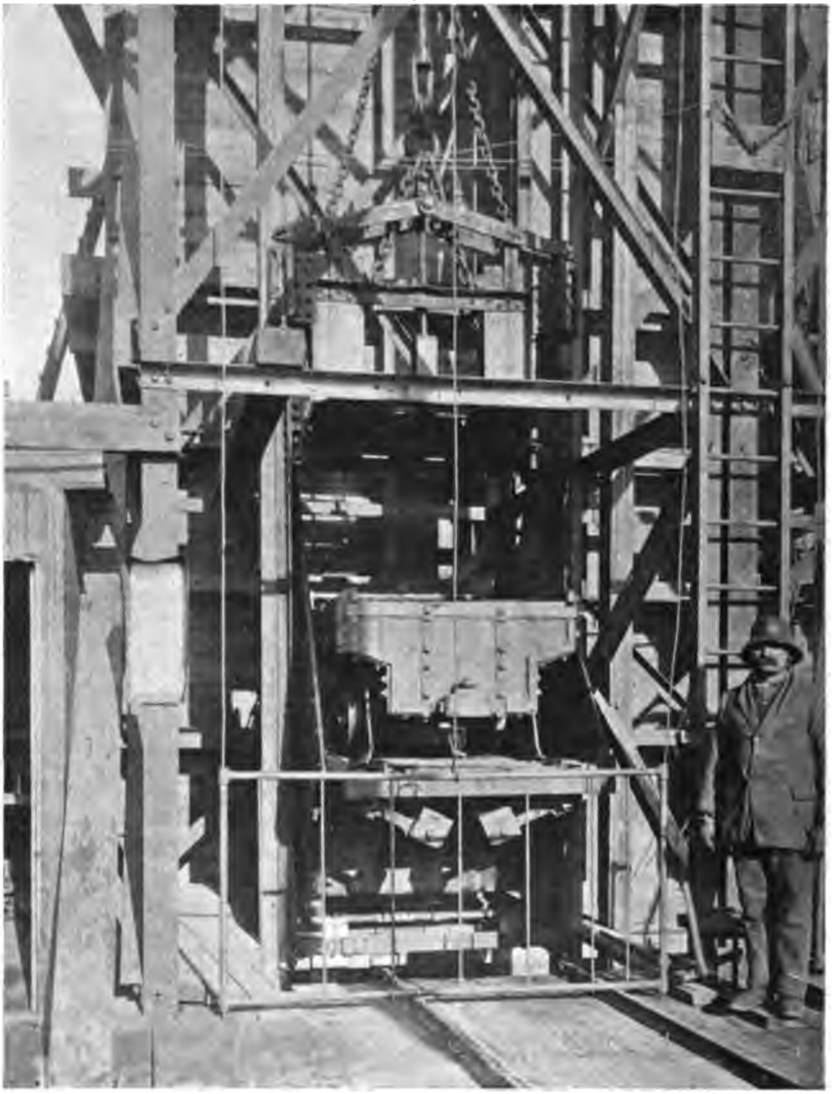


PLATE 199.—Hill View Reservoir. Connellsville Self-dumping Cage and Low Muck Car Used by Dravo Company in Excavating Pressure Tunnels.

in each tunnel with the usual top heading, it was found that progress was slow using this method and the ordinary percussion drill. An attempt was made to better this by the use of the bottom heading and Leyner drills. After the bottom heading was driven by an arrangement of horizontal drill holes which yielded after shooting a circular bottom with flat roof about mid-diameter, the remaining rock could be readily excavated by the use of a few horizontal holes loaded and fired to shoot the upper half onto a heavy timber platform. Under this platform the muck cars were run and loaded through trap doors, thus saving much handling. It was found in some instances that the shooting of the upper headings broke the timber platform, such an accident inconveniencing the work a good deal. South from the downtake shaft, after a few hundred feet, the bottom heading was driven through to the end of the contract and the top shot down and mucked without the aid of the timber platform.

By this method the tunnel was driven to a very true shape, as the perimeter was formed by horizontal holes. In hard rock, with the ordinary top heading method, it is usually found difficult to shape the lower half by the usual vertical holes. From the progress made, it is doubtful whether this method really saved over the top heading, as the cost of moving and replacing the platform, etc., probably more than offset its advantages.

Firing with Fuses. At first, electric firing was used, three rounds of holes being fired in the usual manner; this took from one to two hours, although a ventilating plant of ordinary type was used. To save a portion of this time fuse firing was introduced. All the holes in the heading were loaded at once and exploders inserted in cartridges as usual. Instead of these exploders being connected with electric wires they are crimped to fuses expressly constructed for this purpose. They were heavily wrapped and waterproofed and loaded with gunpowder so as to burn at a uniform rate 24 inches per minute. The cut holes contained the shortest fuses, the side round fuses a little longer, and the trimming hole the longest. All the fuses were lit at once and burned for a sufficient time for the men to leave the tunnel, after which the cut holes would first go off, followed by the side rounds and then by the trimming holes. The man would usually leave about the end of a shift and before the next shift entered the tunnel the air would be clear. The superintendent in charge reports that this firing was invariably successful, no misfiring occurring, and that a great saving of time resulted.

Plate 200.—Excavation of Tunnel by Bottom Heading Methods. Timber platform in position to receive Muck from upper half which is drilled from platform and blasted by use of horizontal holes placed near painted line on perimeter of tunnel.

Leyner Drills. The Leyner drills at first gave considerable trouble, but later it was reported that the parts which formerly broke down after being replaced by special steel castings stood up well, the superintendent claiming that two of these drills could do the work of the four drills formerly used, and even then save some time, eight hours usually being consumed in drillling and blasting a heading. A Leyner drill sharpener was in use for making bits and welding steel. As both the tunnel headings were short, it is probable that they did not give sufficient opportunity to thoroughly test the drills. The average progress made in driving north from Uptake shaft was 110 feet of completed tunnel excavation per month, south of Downtake 150 feet of completed tunnel per month, the Leyner drill increased the heading progress to a maximum of 273 feet per month.

Concreting of Tunnel. The tunnels were concreted in the usual manner, the finished diameter of waterway being 16 feet 7 inches for the Yonkers siphon, and 15 feet for the Van Cortlandt siphon. This allowed an invert 6 feet wide to be laid by the use of continuous wooden strip forms, screed boards, etc. Upon this invert was erected the usual Blaw steel form with carriage, and back of this the arch forms both with carriages on the invert, with platform of both forms connected so that the concrete cars hauled up the incline could supply either arch or side wall, the side walls being used as reservoirs to hold the concrete which could not be placed in the arch. The method was very similar to that described under Contracts 12 and 47. Crusher dust obtained from the Yonkers gneiss was used as sand, but it does not give quite as good a finish to the concrete as when natural sand is used. Using three pairs of trailing arch and side-wall forms, in 20-foot units, no difficulty was experienced in concreting 20 feet per day on the Yonkers siphon and 30 feet on the Van Cortlandt siphon. The actual concreting time was usually eight hours. The concrete was discharged from the mixer directly into Koppel cars on the cage at the top of the shaft and drawn by mules to the foot of the 75-foot incline.

Hains-Weaver Concrete Plant. Near the downtake shaft a full-sized Hains-Weaver concrete mixing plant was erected, equipped with electrically operated stone, sand and cement-bag elevators. This plant, constructed of heavy timber and with the usual hopper and platform, was capable of easily mixing 400 to 500 yards per shift of eight hours. All the concrete used on the dividing wall was mixed here and carried in bottom-dumping double-door Dowd buckets to the site of the work and dumped in the forms with large electrically operated traveling derricks.

Sand-rolling Plant. The stone used in the concrete was largely obtained from the storage pile accumulated by crushing the stone muck as described before. A portion was used for lining the pressure tunnel by the Dravo Contracting Company, and the remainder loaded on cars and fed to the bucket elevator on mixer. Crusher dust and natural sand was used for the fine aggregate. Hillview is remote from good available sand deposits and natural sand is therefore costly on the ground. To meet the situation a sand-rolling plant was erected near the mixer. This plant consisted of a No. 5 McCully gyrating crusher, into which was fed the hard boulders obtained from the excavation. The crushed stone, about 1½-inch size, was fed to a large pair of flat Cresson rolls which rolled the stone into a finer product which in turn was crushed by a second pair of flat rolls to a size supposed to be below ¼ inch. It was found necessary to screen the product again and to send the flat rejects above ¼ inch back to the fine rolls, in the same manner as rejects are recrushed in the main crusher. The foreman stated that about 150 cubic yards of boulders could be turned into sand per day; that the gyratory crusher could do far more than this, but any effort to feed faster would overload the rolls. This supply was not sufficient and it was necessary to purchase natural sand in addition. From the force and plant charges the cost of this artificial sand must be considerable, and it is doubtful whether it is a commercial success. It is reported that the rolls are standing up very well under their severe work, though they are forced to pulverize very tough trap rock.

The glacial drift at Hillview contains considerable ground-up rock, which when washed out by the rain accumulates in the depressions and gulleys as good sand. An attempt was made to wash the drift, using a Weaver sand-washing machine. This succeeded in recovering a quantity of very good sand, but the machine is a small one and it is not known whether the product pays the cost of operation.

Preparing Concrete Bottom for Dividing Wall. After the excavation for the dividing wall was removed by steam shovels, the final trimming was done by hand to about 3 feet below the grade of the reservoir bottom. The dividing wall containing the 12-foot circular by-pass aqueduct was built in two lifts. The bottom lift is $20\frac{1}{2}$ feet high, $34\frac{3}{4}$ feet wide at the bottom and 12 feet at the top, and contains 435 yards in a 30-foot section. The upper lift is 16 feet high and 4 feet wide at the top. As the excavation for the dividing wall was completed, steel pedestal block forms $7\frac{1}{2}' \times 3'$ wide at the base and stepped to $6' \times 9''$ at the top were set to grade and filled with concrete screened to form a portion of the invert of the by-pass aqueduct. They were built $7\frac{1}{2}$ feet apart at first, but later 10 feet, and were carried 90 feet ahead of the wall. The next operation was to cover the bottom with 12-inch concrete for a length of 30 feet and imbed large stones in it.

Forms for By-pass Aqueduct. Upon the invert blocks were erected the full circle 12-foot steel forms built by the Blaw company. The waterway forms were divided into two parts at a point about 3 feet above the invert, the forms being keyed at top and bottom, and the upper and lower parts bolted together through 3-inch beveled steel plates. (See Plate 201.)

The forms were moved on a very ingenious car which ran on inverted angles bolted to the invert form. The car was equipped with jacks at the top and with arms carrying turnbuckles. The top was a double channel forming a track for the chain-block hoists which could be run out about 7 feet at each end beyond the body of the car on its cantilevered track. In moving the forms, the invert forms at the rear of the work were folded and raised by the chain hoists and run through the body of the car on the cantilevered overhead track and dropped into place on the concrete invert blocks. This operation was repeated till the invert was placed for a 30-foot section. An arch section was then lowered on the screw-jacks mounted above the channels and drawn away from the concrete by turnbuckles and the car moved ahead to its new position, where it was raised into position and its fillers again bolted in. The forms were in $7\frac{1}{2}$-foot lengths and were loaded with cars filled with pig iron to prevent flotation.

Outside Forms for Dividing Wall. The outside forms were of steel in 5- or $7\frac{1}{2}$-foot sections extending the full height of bottom lift of the wall and were moved in 15-foot units by the derricks. The forward panel of each setting of outside forms contained bolts with washers imbedded in the concrete to act as anchors when the next forms were moved ahead and bolted to them. Lines of $\frac{5}{8}$-inch cables were used to tie the bottom of the panels together, tapered steel bolts fastened the side panels to the waterway forms, and in

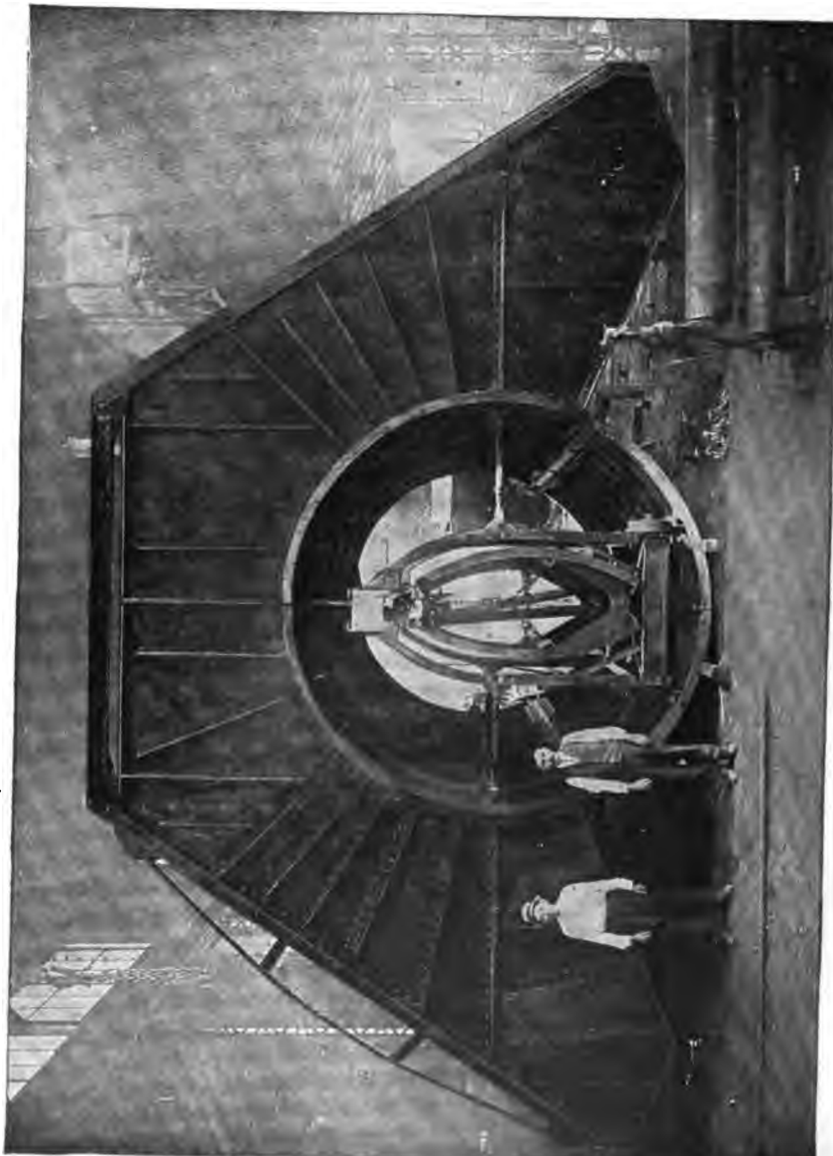


PLATE 201.—Blaw Inside Forms, and Steel Bulkhead for By-pass Aqueduct for Hill View Reservoir as Set Up in Shop. Form-moving Car in position.

addition it was found necessary to stiffen the waterway forms with 12″×12″ timbers.

The bulkhead was of steel and after being assembled for the first time it was moved as a unit. The construction of forms and carriage is shown on Plate 202.

Difficulties Met in Casting Circular Aqueduct. Although the operation of the forms was successful and was performed as required by the specifications, one cannot but wonder at the difficulty of casting a full circular aqueduct in one operation. A circular aqueduct can be very simply obtained by the method used in the pressure tunnels; that is, by casting first an invert strip, then side walls to mid-diameter, and then the arch. This would necessitate two simple forms and carriages. The outside of the wall could also be readily cast by the use of a wooden or steel cantilevered panel form similar to that used for the construction of core walls at Ashokan Reservoir, for the Panama Canal lock walls, and numerous other places, and the dividing wall run up to full height after the arch is cast. The forms for casting the upper 16 feet of dividing wall gave considerable trouble. When first used they were of steel and rested upon bolts set loosely into the concrete wall below and were tied together with ⅝-inch wire rope cables and tapered bolts. The bursting pressure of the concrete was so great, however, as to rupture some of the tie lines, necessitating the use of timber trusses and additional cables. These forms later were entirely rebuilt and stiffened by trusses built up of structural steel.

Progress Made in Concreting By-pass Aqueduct. The concrete was hauled from the Hains-Weaver mixer at the downtake shaft in 1½-cubic yard bottom-dumping Dowd buckets on flat cars drawn to the point of deposit by 3-foot-gauge electric motor cars operated by current from a third rail. Tracks for these cars were constructed each side of the dividing wall as the work progressed. The concrete was deposited in place by electrically operated travelers. A total length of 2188 feet of by-pass aqueduct was built between April 12 and November 25, 1911, at first in 15-foot sections and later in 30-foot sections. A 30-foot section, about 435 cubic yards, was concreted in seven hours. Average progress per month was about 275 feet, about 3900 cubic yards; for two successive months, 390 feet, or 5600 cubic yards. On Contract 11 during the season of 1911 about 1500 feet of ordinary cut-and-cover aqueduct, about 7500 cubic yards, were cast per month of the working season, with a very similar plant.

Plate 202.—Hill View Reservoir. Steel Interior and Exterior Forms, Used for By-pass Aqueduct through Dividing Wall of Reservoir. Invert form in position on pedestal blocks supporting carriage for moving interior forms.

Power House and Auto Trucks. To furnish power for his electric machinery the contractor operated a central generating plant at his camp.

Two 5-ton Mack trucks and one 6-ton Saurer automobile truck were employed to haul cement from the siding at Wakefield on the Harlem Railroad, the trucks also carrying coal and miscellaneous articles.

CHAPTER XIX

CITY TUNNEL—BRONX DIVISION

City Aqueduct. Construction work on the Catskill Aqueduct within the limits of the City of New York was not started until 1911, about four years after work above the city line was under way. The experience gained during the construction of pressure tunnels, and the thorough investigation of the distribution problem of New York City led to the plan of distributing water throughout the City by means of deep tunnels. This, because of its originality, met with a good deal of opposition which took time to overcome. It was fortunate that delay did ensue, as the Rondout siphon in particular was far enough along to serve as an object lesson as to what could be done under conditions more difficult than those likely to be encountered in New York.

Reasons for Adopting Tunnels. The single tunnel to be constructed, varying from 15 feet to 11 feet in finished diameter, will take the place of thirty-two 48-inch pipes or sixteen 66-inch pipes which otherwise would be necessary to carry the flow of 500 million gallons per day and deliver it under the same head as the tunnel. A summary of the reasons which led to the final adoption of the pressure tunnel is here given, taken from the Catskill Water System News:

"When the problem of distributing the 500 million gallons per day Catskill supply within the city, came up for solution, it appeared that there were but two possible ways of doing this. One was to carry the supply in metal pipes, laid in the street close to its surface; the other, through a tunnel deep in the rock. The magnitude and difficulties of the first method can readily be appreciated, when it is realized that it would take thirty-two 48-inch pipes or sixteen 66-inch pipes to carry the flow of 500 M. G. D. and deliver it at the same elevations as would the then-proposed tunnel.

"A summary of the reasons which finally led to the adoption of the pressure tunnel is given below:

1. "That the plan provides for the delivery of all the Catskill water.

2. "That it will serve all the boroughs equally according to their probable future needs.

3. "That the estimated cost of the work under the proposed plan is $25,000,000. The original partial plan now replaced was estimated in 1905 to cost $10,224,000 and that, therefore, the entire plan as now contemplated calls for an increased expenditure of only $15,000,000.

4. "That the estimated cost of the delivery of the full capacity of the Catskill Aqueduct through steel pipes to all of the boroughs of the city is about $47,000,000.

5. "That the plan now proposed is seen from the above figures to be much cheaper than any other plan which has yet been proposed.

6. "That about 25 millions of gallons of pumping to the Brooklyn high service can each day be saved and that about 75 millions of gallons of pumping to the high service in Manhattan and The Bronx can also be each day saved. That the annual cost of this pumping is about $400,000, and that this saving is equivalent to an investment of about $10,000,000.

7. "That private pumping in all the boroughs amounting to about 30 millions of gallons daily, and costing about $1,500,000 each year, can nearly all be saved, and that this saving to the people of the city is equivalent to an investment of about $40,000,000.

8. "That the height to which the delivery under the plan proposed will be made will be approximately 100 feet higher in the Borough of Brooklyn than under the original partial plan, and that this delivery will be made to elevation 260 feet above tide water.

9. "That the proposed plan will provide a much-needed connection between the main water supply systems of the two larger boroughs and that thus an interchangeable use of the waters from the north and those from the east is rendered possible as occasion may require or necessity demand.

10. "That the modified plan will so cross-connect the distributing reservoirs within the city as to make, in case of emergency, any one of them available in any part of the city.

11. "That the modified plan will materially increase the capacity of all existing distribution systems by making various direct connections into the main distribution arteries and thus will result in better protection against fire and a consequent reduction in insurance rates to the people of the city. It will also defer enlargement of the present distribution system which would otherwise from time to time become necessary.

12. "That the tunnel plan is the most permanent type of construction at this time known.

13. "That the proposed plan embraces certain constructional advantages which can be embodied in no other plan, to wit:

(*a*) No streets along the line of the tunnel will be torn up.

(*b*) No streets along the line of the tunnel will be closed.

(*c*) All work on the tunnel will be done under cover.

14. "That while it is proposed to utilize land along the line of the tunnel now owned by the city for park purposes, yet no park space above the surface of the ground will be permanently occupied and the total park area temporarily occupied will be very small indeed.

15. "That the tunnel plan offers greater insurance against breakage than does any pipe plan, and that on such a plan both the cost of repairs and maintenance are a minimum.

16. "That the tunnel is not a novel one in view of the many deep tunnels and mines that have been elsewhere driven, completed and operated, a notable example close at home being the deep tunnel on the New Croton Aqueduct from Jerome Park to 135th Street, Manhattan, a distance of 7 miles.

17. "That the borings and studies which have been made show conclusively that no unusual or untoward conditions exist or are to be expected.

18. "That in view of the experience gained on other precisely similar tunnels along the line of the work under the board's direction, said tunnels lying under the Rondout, Wallkill, and Moodna rivers, and under Croton Lake, aggregating about 14 miles in length, the proposed tunnel is entirely feasible of construction.

19. "That in view of the actual progress of the above-mentioned tunnels and on other tunnels elsewhere, the work can be completed within four years.

20. "That the pipe line under the Narrows and the portion of the tunnel under the East River can be completed in advance of the rest of the work, thereby affording relief and additional security to the Boroughs of Richmond and Brooklyn, respectively.

21. "That the water from the tunnel system will be delivered into the present distribution mains through pressure regulators at whatever pressures may be most desirable.

22. "That by lowering the elevation of delivery it would be possible, by the modified plan, to deliver the entire quantity of 500 million gallons daily into the Borough of Brooklyn.

23. "That the modified plan will place the delivery system of

the city on a plane superior to that of any in the world, and that so nearly as can now be foreseen, no material changes or additions will be necessary for many years to come.

24. "That the modified plan calls for the acquisition of only about 1640 lineal feet of right of way from private parties or corporation, since for the balance of its length it lies under parks and public streets."*

Location of City Aqueduct. The location of the city aqueduct is shown on Plate 203. It continues the tunnel leading from Hill View reservoir south through the boroughs of The Bronx and Manhattan and Brooklyn, where it forks, leading to two terminal shafts, each equipped with two 6-foot riser pipes, the tunnel itself gradually reducing from 15 feet at the upper end to 11 feet at the terminal shafts. From the terminal shafts pipe lines are to be laid into the Borough of Queens and through the Borough of Brooklyn under the Narrows to Silver Lake reservoir in the Borough of Richmond, which is the terminus of the Catskill Aqueduct, 120 miles from its source.

Narrows Siphon. The pipe under the Narrows is to be a flexible jointed cast-iron line 10,000 feet long, laid in water of a maximum depth of about 60 feet, and subjected to a current of more than 3 miles an hour with short quiet periods between tides. It was found by various experiments with anchors that the pipe would be sufficiently protected by 8 feet of silt. The requirements of the War Department will necessitate a trench 28 feet deep for a considerable portion of the work which will have to be constructed in the main channel of New York harbor.

Use to be Made of City Tunnel. Provisions are to be made for draining the 17½ miles of tunnel for inspection or repair. At shafts 11 and 21 at deep points in the profile caused by depressions at Harlem and East River are to be drainage shafts similar to those on other siphons of the aqueduct. To enable the tunnel to be drained in sections two of the shafts are to be equipped with valves built in the main tunnel, which will enable portions of the tunnel to be examined without putting it all out of commission. At Shaft 3 a connection will be made to the Croton Aqueduct system through an 8-foot tunnel extending to the gate house at the north end of the Jerome Park reservoir. This tunnel will be capable of delivering 300 million gallons daily to and from the reservoir. At Shaft 10 a future connection can readily be made with the 135th Street gate house and terminal shaft of the New Croton Aqueduct.

* See also volume issued by Board of Water Supply in 1912, entitled "Reports, Letters, etc., on the City Tunnel."

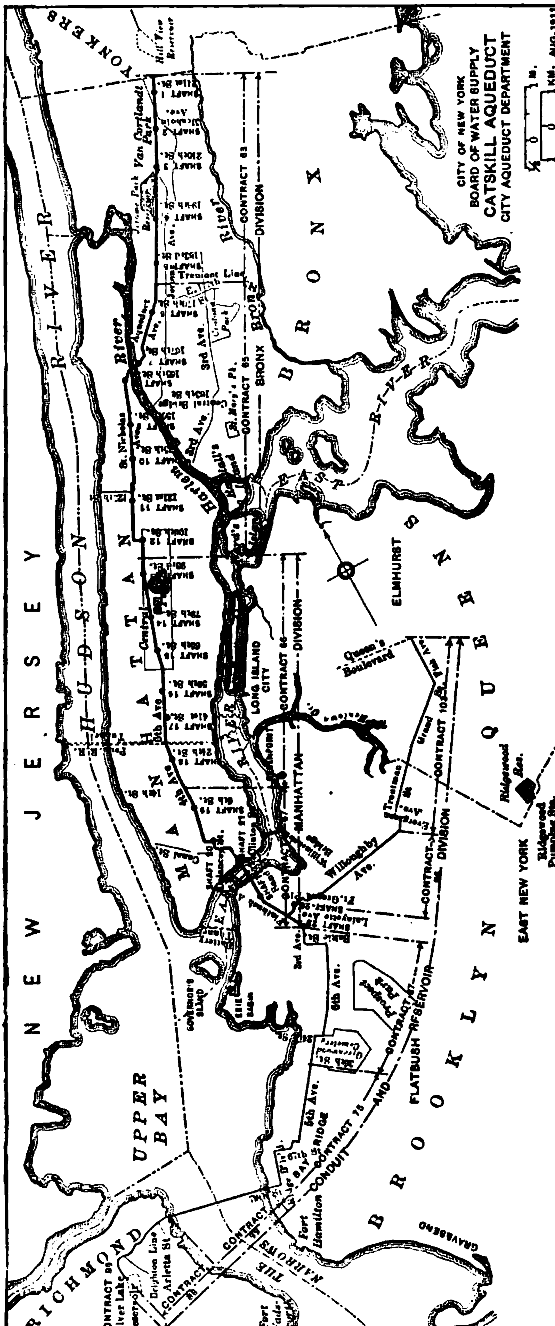


PLATE 203.—Map Showing Location of Catskill Aqueduct within Limits of New York City. Pressure Tunnel Extends from Hill View Reservoir to Shafts 23 and 24 in Brooklyn. Thence to Richmond and Queens in pipe lines of steel and cast iron.

Of the twenty-four shafts, twenty-two have connections to the present distribution system. Thirteen have single 48-inch risers for this purpose, six have two 48-inch risers, and three have two 72-inch risers. Shafts 14 and 18 have in addition to two 48-inch risers a 66-inch section valve across the main tunnel. All but two of the shafts are circular in shape, and are lined with concrete during sinking. After completion of work in the main tunnel, the upper 100 feet of the shaft will be concreted in solidly with the steel riser pipes, to the bottom of which will be attached conical riser valves. The riser pipes terminate in a bronze shaft cap, which is essentially a 48″×30″ or 72″×48″ tee. The water passes from this throuhg the gates and pressure regulating valves to the city mains.

Profile of City Tunnel. The tunnel was fixed at a depth to give at least 150 feet of satisfactory sound rock cover at all points. Generally the tunnel is from 180 to 300 feet below the surface, except for two stretches at the Harlem and East rivers. The Harlem River depression reaches a depth of 450 feet, the East River depression a depth of 730 feet. The Harlem River depression is reached by inclines, the East River depression by step or two-level shafts.

Award of Contracts, City Tunnel. All the work on the city tunnel, Catksill Aqueduct, was advertised under four tunnel contracts, the bids for which were opened on the same day. The contracts were shortly afterwards awarded to the lowest bidders for a total of $19,085,000. With the exception of contracts let for the construction of subways, this represents the greatest amount of work contracted for at one time by the City of New York. The contractors were experienced, two of them having other contracts on the aqueduct.

Restrictions of City Work. The conditions which govern construction work of this class within the city limits are very different from those outside, chief among them being: (1) Restricted areas for operation at most of the shaft sites; (2) restrictions imposed upon blasting and handling explosives, blasting generally being prohibited between 11 P.M. and 7 A.M. until tunnels were 250 feet in from shafts; (3) disposal of spoil. At a few of the shafts in the Bronx low areas were filled in adjacent to the shafts, and at other places some of the spoil was taken to Riverside Park for fill back of the bulkhead line. At many of the shafts, however, the muck is loaded into trucks and dumped into scows and disposed of at sea. This involves a heavy charge, and also means that stone from shafts and tunnels which in the country would be crushed and used for concrete, is wasted in the City because of the small shaft areas and the nuisance from the operation of crushers. Due to the higher cost of living in the City and to the strength of labor unions, the pay of the men averages considerably higher than in the country. There are also restrictions on Sunday work caused by City ordinances and double pay for union men.

Advantages of City Work. On the other hand, there are advantages connected with City work of this class, a very important one being the ease of obtaining skilled tunnel men, from superintendents down. New York and its vicinity has been the scene of extensive tunnel operations since the beginning of the work on the New Croton aqueduct in 1890. The thirty miles of tunnel on the New Croton aqueduct was the means of training many men; this was followed later by tunnel and rock excavation on subways, and a little later by the Pennsylvania tunnels, and finally by the aqueduct tunnels. Then, again, labor camps are not necessary, with all their attendant worries.

Electric Power. The contracts provide that the plants are to be electrically operated, the Edison Company promising in advance of letting the contracts to sell electricity at the following rates:

6600 volt A.C.	1 ct. per kilowatt hour, plus.
Maximum demand per kilowatt for 5-minute peak load	$20 per year per kilowatt.
Direct current	2½ cts. per kilowatt hour (straight charge).

Electric power in New York is very reliable, due to the numerous power-houses which are tied in to each other, so that any one district can be supplied from several sources. The use of electric power, more than anything else, has enabled the contractors to make good use of the small areas allotted to them at the downtown shafts.

Benefits Gained by Former Experience. The contractors on the City aqueduct were in a very favorable position due to the experience gained on aqueduct work above the City line. The methods of shaft sinking, tunneling, and concreting were thoroughly tested and developed, so that this work could proceed with but little delay. The progress made in the methods of shaft sinking was particularly beneficial to the City contracts, as shown by the high average progress made at the shafts, although they were sunk in large part by tunnel men who, however, had learned the methods introduced into this section by the older shaft-sinking organizations.

Comparison of Central and Isolated Compressor Plants. Opportunity is given on these contracts to study the relative advantages of central and isolated compressor plants, all the plants being electrically operated except that for Contract 63. Mason & Hanger transferred their steam plant from the Moodna siphon to Van Cortlandt Park where a suitable site was found. The only other central plant is that which supplies three shafts in Central Park, the others being isolated electric plants. The central plant has the advantage of economy of operation and can take advantage of the average load, particularly that imposed by numbers of air drills operating irregularly in tunnels. The isolated plant has the advantage that it is close to the point where the power is to be used, eliminating delays caused by long pipe lines. The isolated plants can be shut down one by one as the work at a shaft is interrupted or completed, while a central plant has to be operated until the end of the entire work. With isolated plants at each shaft there is not the same tendency to waste air as with the central plant, for which the individual superintendent has no direct responsibility.

CONTRACT 63

Features of Contract 63. The tunnel work of the City aqueduct is divided into two divisions, Bronx and Manhattan, each of which contains two contracts, known as Contracts 63, 65, 66, and 67, as shown on the accompanying map (Plate 203). Contract 63 continues the pressure tunnel from Hillview reservoir for about 4 miles. The tunnel is being constructed from five circular shafts about 230 feet in depth. Each shaft, except No. 1 and No. 3, is to contain a 4-foot circular riser and a subsurface chamber equipped with controlling devices for admitting water under any desired pressure to the city mains. Shaft 1 is a purely construction shaft, but is circular and lined with concrete. This marks a decided advance in shaft construction, all previous construction shafts on the Catskill Aqueduct being rectangular and timbered. It is now known that a circular shaft can be sunk and lined with concrete at an equal or less cost and with greater speed.

At Shaft 3, which is to contain two 72-inch risers, a connection will be made to the Jerome Park reservoir through an 8-foot tunnel constructed to a gate house. This tunnel will be capable of delivering 300 million gallons, which will be measured by a Venturi meter concreted in the tunnel.

Venturi Meter in Tunnel. Another Venturi meter is to be constructed in the main tunnel upstream from Shaft 2. The concrete-lined tunnel will be contracted in the usual manner on each side of a bronze throat-casting about 8 feet in diameter. Three-inch bronze Piezometer pipes will be concreted in the tunnel and in the shaft, operating a Venturi recording meter at the top of the shaft, to register the differences in head on each side of the throat casting. The wonderful adaptability of the Venturi meter is shown by its construction 230 feet below ground. This meter is shown on Plate 204.

Contract Prices. Contract 63 was awarded to Mason & Hanger, June 1, 1911, for a total of $3,709,000, some of the items being as follows:

Shaft in earth, per linear foot	$292.00
" rock "	310.00 to 335.00
Tunnel excavation, per cubic yard	8.30
Tunnel concrete, per cubic yard	6.75
Shaft concrete, per cubic yard	9.50
Forms for lining pressure tunnel	4.00
Cement	1.50

Plant and Shaft Conditions. The work on this contract approximates work in the country. At three of the shafts the excavation is spoiled in adjacent park areas, and the tunnels are driven by power furnished from a central plant, previously used on Contract 20. Shafts 1 and 2 were sunk by a plant and organization furnished by Smith & Powers; 4 and 5 were sunk by the Dravo Contracting Company, and Shaft 3 directly by the principal contractor. Temporary plants were installed at the shafts and continued in use until the shafts were down to grade or until the central power plant was in operation. The plant at Shaft 1 furnished air for both Shafts 1 and 2. This consisted of three 75 H.P. boilers and two compressors, one Ingersoll-Rand and one Sullivan, each of 550 cubic feet per minute displacement.

Shaft 1 Sinking. Shaft 1 was sunk through Yonkers gneiss, the average weekly progress being about 12 feet, and the maximum about 22 feet. The rock, although sound and hard, was very seamy, particularly near the top, making the shaft wet, the flow being at a maximum 39 gallons per minute. The lining of this shaft with concrete was of considerable advantage, cutting off the larger part of the inflow. No attempt was made to secure a particularly tight concrete, as the shaft was later on to be refilled.

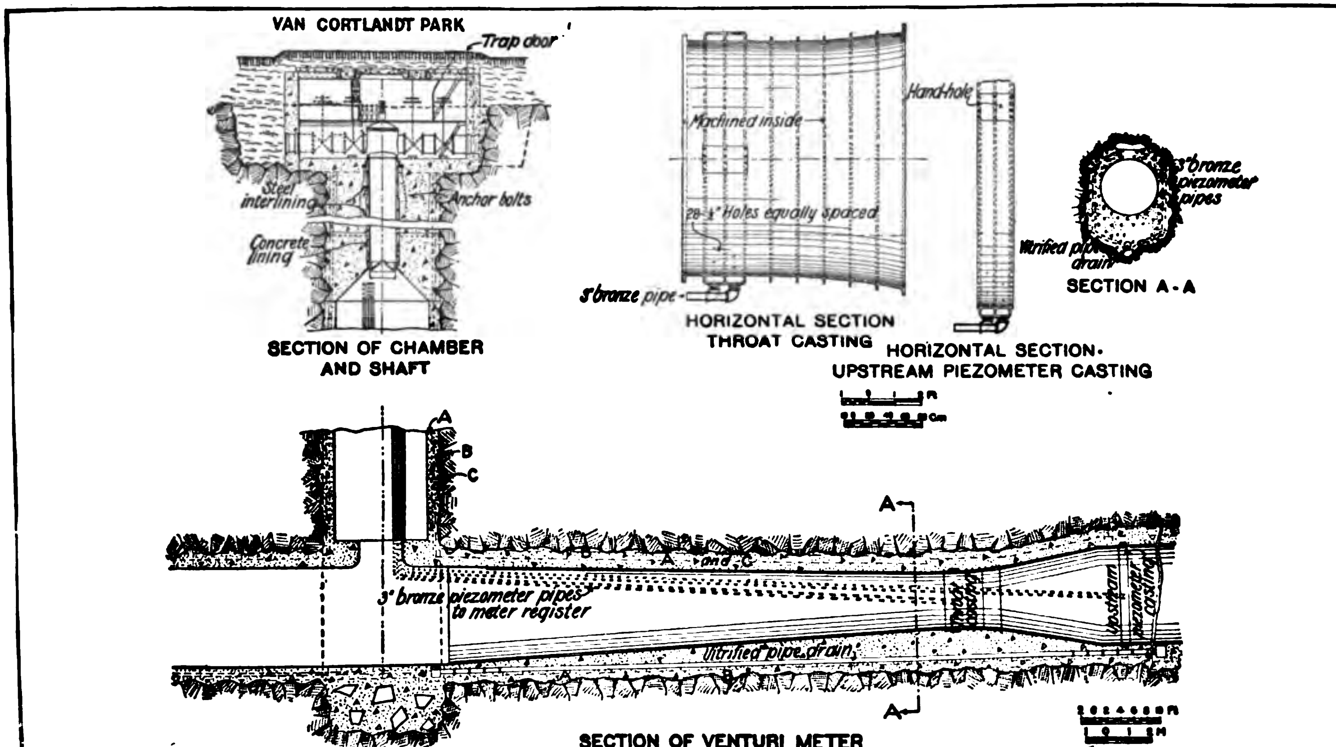


PLATE 204.—Venturi Meter in Pressure Tunnel, City Aqueduct. Recording apparatus is to be placed in chamber at top of adjacent shaft.

Shaft 2 Sinking. Shaft 2 was sunk in material similar to Shaft 1, and was also quite wet. The placing of the concrete lining here was done with considerably more care than in Shaft 1, as this will be used as a waterway. Excessive water was prevented from dropping into the forms by sheds constructed of tar-paper and sheet iron, and leaks in the rock were carried through the concrete forms by the use of drip pans and pipes. Upon stripping the forms the concrete was found to be excellent, very little water coming through the body of the concrete. In this shaft the average weekly progress was about 15 feet, the maximum 22.

Sinking Shaft 3. At Shaft 3 a large rock excavation in open cut was necessary to provide room for the chamber and connections to the Jerome Park reservoir. This excavation was timbered and a circular shaft sunk below and concreted in the usual manner. Good progress was made here, the average weekly progress being 15 feet, the maximum progress 33 feet. Excellent work was done at the shaft, which was started late in July and the headings turned early in December, 1911. This shaft, about 19 feet in diameter, was excavated by means of rectangular cut and relief holes. The eight cut holes were 8 feet deep and in rows 4 feet on each side of the center line. The next round was the relief, also of eight holes in rows 2 feet from the cut holes. The third was the trimming round, consisting of eighteen vertical holes about 6 feet deep, which gave the correct shape of the shaft. About 5 feet was pulled at an advance, using about 2.6 pounds of dynamite per cubic yard. The method of placing the cut and relieving holes in parallel rows is rather unusual in circular shafts, the usual plan being to drill three circular rows of holes, though it is quite common to drill the cut holes in parallel rows. The progress made at this shaft is shown in Plate 205, the method of excavation in Plate 206.

Sinking Shaft 4. At Shaft 4 the Dravo Construction Company installed a temporary plant to supply power for both Shafts 4 and 5. The main features of this plant were two 100-H.P. boilers, and one Ingersoll-Rand cross-compound air compressor of 1500 cubic feet displacement. The upper portion of the shaft was sunk by the aid of a stiff-legged derrick which was later replaced by temporary head frames. The equipment at Shafts 4 and 5 were six to eight $3\frac{5}{8}$-inch Sullivan or Ingersoll piston drills. After excavating and timbering 14 feet of earth overlying the rock at Shaft 4, very good progress was made for the next 150 feet, the maximum weekly progress being 32 feet. The diameter of this shaft is 17 feet 6 inches to B line, and was excavated by three circular rows of holes on $4\frac{1}{2}$-foot,

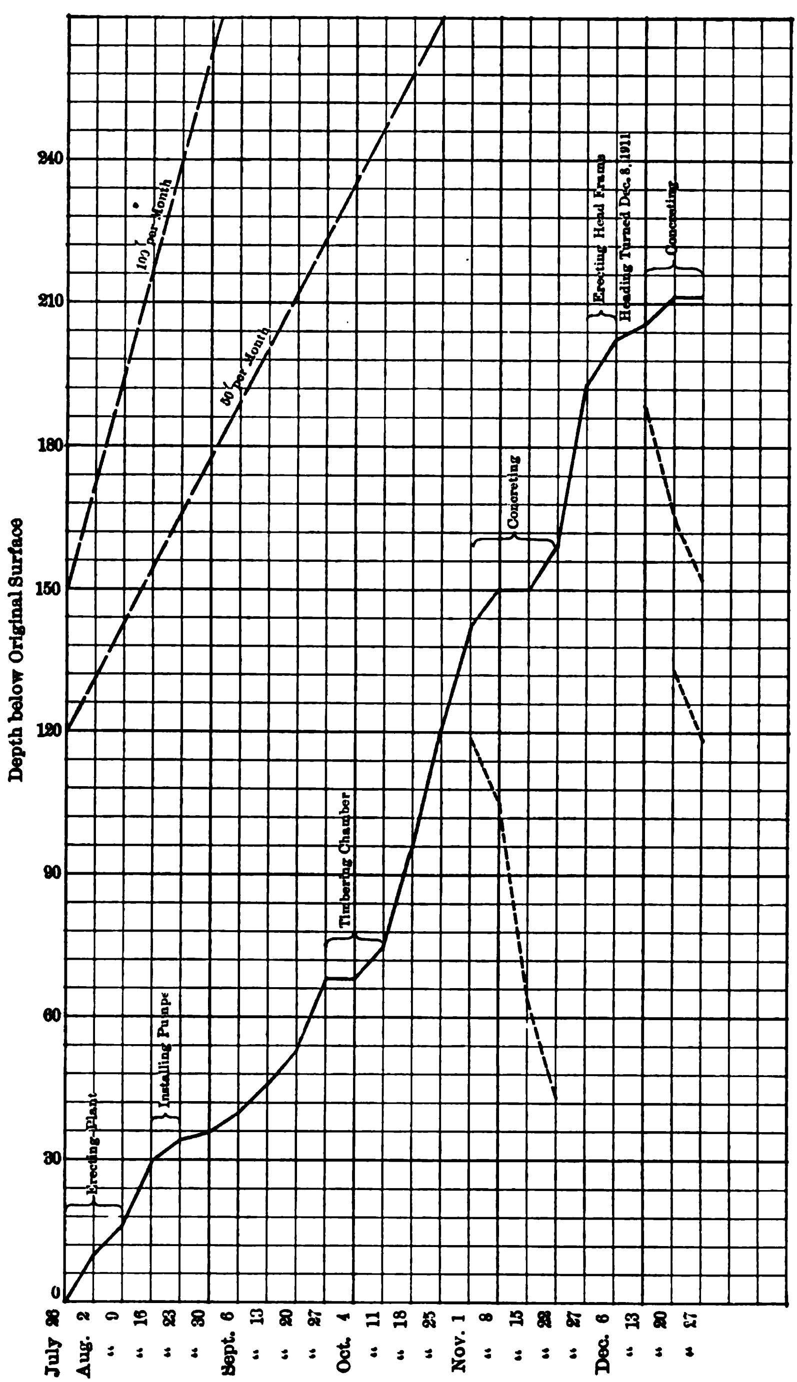
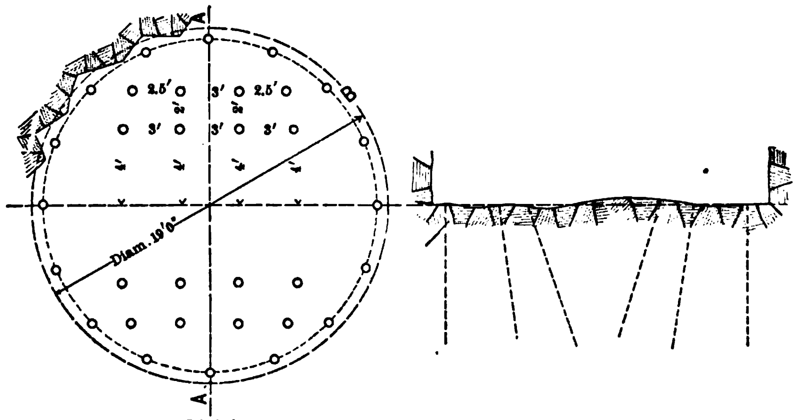


PLATE 205.—Contract 63. City Aqueduct Tunnel. Diagram of Progress of Sinking Shaft 3. Dotted lines show progress in placing concrete lining while sinking was interrupted.



PLAN SECTION A-A

PLATE 206.—Contract 63. Arrangement of Drill Holes and Method for Sinking Shaft 3.

	Holes Drilled.							Powder Used (lbs.).		Aver. Pull.	Cu. Yds. per Ad-v'nce	Pow-der (lbs.) per Cu. Yd.
	Number.			Depth.			Incli-nation.	Aver. per Hole.	Aver. To-tal.			
	Max.	Min.	Aver.	Max.	Min.	Aver.						
Cut...........	8	8	8	8	8	8	27°	5	40	5		
Relief.........	8	8	8	6	6	6	10	4	32	5	55	2.62
Line...........	18	17	18	6	6	6	None	4	72	5		
Total........	34	33	34	220	214	220	......	....	144			

Above is for 15′ 6″ diameter shaft.

TYPICAL FORCE

Shift.	Time.	Class of Work.	Supt.	Ass't. Supt.	Timekeeper.	Shift Boss.	Mechanic.	Pipeman.	Hoist Run.	Topman.	Drill Runner.	Drill Runner Helper.	Muckers.	Blacksmith.	Blacksmith Helper.	Laborers.
1	8–4	Mucking....	1	...	1	1	...	1	1	1	3	...	10	1	1	2
2	4–12	Mucking and drilling....	½	½	...	1	...	1	1	1	5	5	5	...	...	2
3	12– 8	Drilling.....	...	1	1	1	...	1	1	1	5	5	...	1	1	

7-foot, and 8-foot radii. The first row of holes 8 feet deep was drilled to an inward slope of 1 to 4, the second row 8 feet deep was drilled to an inward slope of 1 to 2, the third row of holes 6 feet long was drilled vertically. The two outer rows contained seventeen holes and the inner nine. All the holes were drilled in one shift by six drill runners and helpers. The next two shifts were engaged in shooting and mucking, eight men working in each shift. This rotation was maintained, so that an advance of about 6 feet per day was made. This was the standard method of the Dravo Contracting Company and one well adapted to city use where blasting is restricted to certain hours.

On Contract 63 the best monthly progress in shaft sinking was 99 feet at Shaft 4.

Grouting Water-bearing Rock. The shaft was dry to a depth of 150 feet, when 120 gallons of water per minute flowed from the drill holes. This decreased in a few hours to about 50 gallons. Pipes were inserted in the holes in the usual manner, and 46 bags of neat cement grout was forced in at high pressure, using a Caniff grouting machine. This cut off the flow completely and sinking was resumed. At a depth of 181 feet water, under pressure of 70 pounds, was again struck by the drills. There being no large pumps at hand the holes were plugged one by one as the water was struck, and no determination of the possible inflow made. Encountering water in this shaft gave a good deal of concern, as it is alongside the Jerome Park reservoir, and the hydrostatic pressure was found to correspond with its water surface, It was feared that the water encountered came from the reservoir through seams which might have been opened in this rock by the heavy blasting during the reservoir construction. An analysis of the water in the shaft showed, however, that it differed from the Croton water by containing a larger quantity of solids. The drill holes where water was encountered were grouted and the flow cut off. Fourteen-foot pilot holes were next driven vertically, again striking water, and indicating bad seams, as pieces of rock up to 1 inch in diameter were carried through the holes. These holes were grouted under a pressure of 240 pounds obtained from a Westinghouse high-pressure compressor. A 5-foot sump was then shot, exposing a 2-inch grouted seam, and disintegrated material well grouted. A row of 16-foot holes 18 inches on centers was put down around the perimeter of the shaft and grouted. Nine yards of grout were used in these holes, much of which leaked into the shaft. A concrete blanket was then put over the bottom of the shaft to hold the grout, but this was ineffective and the sinking was resumed. The maximum flow of water encountered after sinking was resumed was about 100 gallons per minute. The operation of grouting took about eighteen days, during which 850 batches of about 55 yards were placed, mostly in two holes. The rock of this shaft is largely a sound Fordham gneiss, a dark banded rock. At the point where the grouting was done the rock was ground up into a very light sandy material easily penetrated by the grout, which partly solidified the sand and partly accumulated in rather large masses and layers by forcing the sand to one side.

Success of Grouting. It is probable that the crushed zone, which varied from a few feet to 20 feet in thickness, could have been penetrated with the aid of a larger pumping equipment, but power for this was not then available, due to the non-completion of the main plant. Although eighteen days were taken in the grouting, this was a much shorter time than would ordinarily take to install a new pumping plant. After excavating 10 feet below the disintegrated area into the solid rock, the shaft was concreted. For 20 feet a special section of 24 inches minimum thickness of concrete, reinforced by 1-inch rods placed about 12 inches center to center vertically and horizontally, was placed. To take care of the water while concreting, the disintegrated area was covered with sheet iron. The spaces back of these pans were packed with rock, grout pipes leading the water through the forms. In this manner a very good lining was placed, and one which readily withstood a pressure of 77 pounds, as shown by a gauge after the pipes were plugged. The dry packing back of the concrete is to be grouted. As the bad ground encountered in this shaft occurred near the roof of the tunnel, the shaft was deepened 14 feet to bring the tunnel into sound rock. The average progress in sinking this shaft was 13 feet per week.

The work at this shaft illustrates very well the advantages of grouting to pass water-bearing seams, and more particularly the advantage of concreting the shaft while sinking. Were this shaft timbered, a great deal of the water would have escaped, to the detriment of the work below.

Shaft 5. Excavation of Chamber, Steel Piling. Shaft 5, the last on Contract 63, located at 183d Street, is very close to the old Croton Aqueduct, the invert of which is slightly above the top of the shaft, making cautious work necessary to prevent undermining that structure. For the chamber excavation a 4-inch tongue-and-groove sheet piling was used to a depth of 20 feet with practically no loss

PLATE 207.—Shaft 5. City Tunnel. View Showing Framework and Steel Piling in Position.

of ground. Below this there was encountered 14 feet of water-bearing clay, sand, gravel, and boulders, which was penetrated by steel sheet piling supported by timber sets 2 feet 6 inches center to center. The piling was driven by pneumatic hammers, the points of the piles being kept about 5 feet in advance of excavation. The rock was reached without much trouble, but it was found that the sheet piling was forced out of line in many places by boulders; and portions in the way of subsequent concreting were cut off by the oxy-acetylene torch. Despite claims to the contrary, steel sheet piling cannot penetrate bouldery ground without injury unless considerable care is taken. Individual members should be carefully driven, particular pains being taken to stop after boulders are encountered. By carefully driving those not in contact with boulders, sufficient excavation can be safely taken out to enable the boulders to be removed in advance. After sinking the rock shaft a short distance the upper concrete was placed to the elevation of bottom of shaft chamber, that portion of the concrete lining opposite the steel piling being reinforced by horizontal and vertical steel bars, after which the steel sheeting was pulled and the space grouted. Shaft 5 in rock was sunk by the same method used at Shaft 4.

Power Plant. At the date of this writing all shaft excavation on Contract 63 has been completed and the tunnels are well under way. Cages and plant similar to that in use on Contract 20 (Moodna siphon) are in operation. Power is supplied from a main tunnel plant located in Van Cortlandt Park with a convenient railroad connection. This plant contains as its essential parts:

2 Keeler water-tube boilers	300 to 600 H.P.
4 Heine water-tube boilers	250 to 1000 H.P.
2 Sullivan cross-compound compressors, 2500 feet displacement	5000
2 Ingersoll-Rand cross-compound compressors, 2500 feet displacement	7500
Total (cubic feet per minute)	12500

It is said that this plant, which is an economical compound-condensing steam-driven plant, furnished compressed air at less cost than the electrically driven plants, on other contracts, using current at City rates as given.

Tunnel Plant. After the shafts were sunk the main contractors erected wooden head frames in which were placed balanced $5' \times 8'$ self-dumping Eagle cages similar to those used on the Moodna siphon. Low, convenient cars were used for mucking and were hauled by mules to the shafts. At Shafts 2 and 4 the tunnel muck as dumped from the cages is crushed directly by conveniently placed McCully gyratory crushers and the crushed rock and dust distributed into large piles by a long belt on trestles. At Shafts 1 and 3 the muck is dumped in low areas in the adjacent parks. It is hauled away from Shaft 5 in wagons.

Tunnel Driving. The rock at Shafts 1 and 2 proved to be very hard to drill and quite wet in seams and broken areas. The tunnel progress during 1912 averaged about 122 feet per month in each heading.

At Shafts 3, 4, and 5 the formation of Fordham gneiss was tunneled. This rock proved to be rather hard to drill, average time to drill heading being about 12 hours, and the average weekly progress per heading being about 40 feet when the rock was sound. In the north heading of Shaft 3 and both headings of Shaft 4 very poor, broken, and wet ground was encountered, but successfully passed by the use of temporary timbering and steel roof support of two types—longitudinal steel I-beams with channel lagging on wooden bents and steel bents lagged with small I-beams and dry packed. The poor ground encountered south of Shaft 4 is supposed to be the same zone of rock successfully grouted off in the shaft. This zone yielded 300 to 400 gallons of water, which was easily handled by an outfit of Lawrence 250 g.p.m., and Worthington 450 g.p.m., electrically driven centrifugal pumps. The methods of tunnel driving pursued on Contract 63 are very similar to those described under Contract 20, Moodna siphon. For excavating a pair of headings at each shaft, 3 drilling shifts of 7 drillers and helpers and 3 mucking shifts of about 20 muckers were employed per day. It took from 8.5 to 11 hours to drill the heading, and about 12 advances of from 6 to 7.5 feet were made per week, using the usual top heading and bench method. The heading drills were mounted upon 3 columns. Usually 2 tripod drills were used for bench.

Contract 65

Work and Prices. This contract continues the tunnel southward from Contract 63 at 179th Street, in the Borough of the Bronx, a distance of 5.36 miles to a point in Manhattan at West Ninety-ninth Street in Central Park. It contains seven shafts, varying in depth between 246 and 461 feet, aggregate depth 2552 feet. The shafts are spaced from 2500 to 5100 feet apart, six of them being provided with 4-foot risers, Shaft 11 being a drainage shaft. The tunnel lying north of Shaft 10 (3.35 miles) will be 15 feet finished diameter; south of this point the tunnel is 14 feet in diameter. This contract is the longest of any on the city aqueduct, and the total contract price, $5,590,000, is the largest. It was awarded to the Pittsburgh Contracting Company, June, 1911. Some of the items are as follows:

Shafts, per linear foot	$400.00
Tunnel excavation, per cubic yard	7.75
Tunnel and shaft concrete, per cubic yard	8.00
Forms for lining pressure tunnel and shafts, per foot	10.00
Cement, per barrel	1.35

With the exception of the tunnel near the East River, a portion of the tunnel of this contract under the Harlem is the deepest on the City aqueduct, the lowest elevation being reached being −365 feet at the drainage shaft in Morningside Park near 121st Street.

Electric Equipment. The Pittsburgh Contracting Company has been most original in its methods of construction both on cut-and-cover aqueduct and tunnels, as shown by its work in three of the aqueduct contracts, 45, 52, and 65. The general superintendent considered the test of electric drills as made in Contract 52 sufficiently successful to warrant equipping Contract 65 with a complete outfit of electrically operated machinery, eliminating all compressor plants and compressed-air machinery. To operate the electrical machinery three transformers stepping the current down from 7200 to 2200 volts, three transformers stepping the current down from 2200 to 220 volts, and one four-panel switchboard equipped with circuit breakers, switches, etc., were installed at each shaft.

Fort Wayne Electric Drill. At the outset all the shafts were equipped with electric drills of different types with the purpose of deciding which one or ones would be suitable for the work. The Fort Wayne electric drill is a hammer drill operated by a belt from a motor attached to the drill. The steel used is twisted and rotates like an auger while drilling. It was found that this type of drill could not bore holes in the medium-hard Manhattan schist with any speed and after a trial of a few weeks its use was discontinued. It is stated that this drill gives satisfactory service while operating in soft rocks, particularly for horizontal holes. It is in effect an electrically driven steel auger which is repeatedly tapped while being rotated.

PLATE 208.—Proposed Structure Over Drainage Shaft at Shaft 11, Morningside Park and 121st Street.

Temple-Ingersoll Electric Air Drill. The electric air drill made by the Ingersoll-Rand Company was tried for a short time at Shaft 6, but it was found to occupy too much space at the bottom of the shaft and its use was discontinued. The Temple-Ingersoll or electric air drill is operated by a small pulsator mounted upon a little truck. As the pulsator oscillates the air is compressed alternately on each side of the piston of a simplified air drill with which it is connected by two lines of air hose. The pulsator is driven by an electric motor connected to the main feed wires. The air compressed is not freed, but is repeatedly used in a closed circuit. The drill used is an air drill modified by omitting the valve chest and valve, also the springs, side rods, etc., both cylinder heads being solid. This drill has given good service where there is plenty of room for the puslators, air pipes, and electric connections, and is particularly designed for work in large "rooms," in mines and in headings where only one or two drills are necessary and where there is very good ventilation, the drill exhausting no air. From the experience at Shaft 6, its use could not be recommended for shaft sinking, although in Colorado shafts have been sunk with the electric air drill.

After a time the use of the electric drills was confined to Shaft 9 and 11. At Shaft 9 the Dulles-Baldwin drill was used; at Shafts 11 the Pneumelectric.

Dulles-Baldwin Electric Drill. The Dulles-Baldwin is a large-size piston drill upon which an electric motor is mounted, so as to operate a piston which compresses the air in a cylinder similar to that of an ordinary piston drill. At each operation of the electrically operated compressor piston, the piston of the drill is driven downward, and on the return stroke air is admitted below the piston and again compressed in the down stroke. An adjustment is provided by which the length of the stroke is regulated. The Dulles-Baldwin drill appears to be the simplest type of electric drill in the class where the motor is directly mounted upon the drill. It strikes a hard blow and can drill at a fair rate of speed. Its disadvantages will be given later. At Shaft 9 the Dulles-Baldwin drill has been in use for about six months, during which time it had been remodeled and practically rebuilt, as weaknesses developed from time to time. The progress at the shaft with this drill has not kept pace with the other, but it was claimed that the work here was intended to develop the drill and to perfect it for its proposed use in the tunnels to be driven after the shafts are down. The Dulles-Baldwin drill appeared to be well made, but it was heavy—575 pounds including a 3-H.P. removable motor (140 pounds)—required constant attention and suffered from motor troubles.

Pneumelectric Drill. The Pneumelectric drill is an electric hammer drill corresponding to the Leyner drill. Mounted upon the back of the drill is a motor which operates a piston which compresses air back of a hammer which strikes an anvil block which in turn strikes the end of a hollow drill rod, as in a "Jap" drill. The hammer is returned in the up-stroke by a partial vacuum caused by the return of the compressor piston. Through the anvil blocks a fine stream of water is fed through the hollow steel, cooling the bit and clearing the hole of chippings. A water connection is provided on the drill cylinder fed by a flexible hose attached to a water main under pressure. This drill is quite complicated and looks light, but can drill at a fair rate of speed. At Shaft 11 the Pneumelectric drill has maintained a fair progress, but as at Shaft 9, the work here was intended to develop the possibilities of this drill and to perfect it for future use in the tunnels. A large number of Pneumelectric drills have been tried out at Shaft 11 and there was a large equipment of drills on hand (about 22) with mechanics specially designated to take care of them. As in the case of the Dulles-Baldwin drill, this drill has been entirely remodeled during the few months of this work. This drill has the disadvantage for shaft work that all the water used to clear the bit has to be pumped from the bottom of the shaft, and the water lines introduce further complications.

Advantages of Electric Drills. Credit must be given to the Pittsburgh Contracting Company for their patience and persistence in trying out the electric drill. The electric drill has obvious advantages well worth striving for, viz.: (1) It simplifies the work by rendering unnecessary compressor plants and pipe lines; (2) it is much more economical in power while working. It is claimed that electric drills use one-third to one-fourth of the power consumed by air drills. They are particularly advantageous in locations within the reach of electric power lines from which current can be obtained at favorable rates. The advantages cited have long been recognized, and there are numerous records of previous efforts to use and perfect these drills. As long ago as 1879 Siemens-Halske built a percussion electric drill. Rotary drills or augers driven by motor-driven flexible shafts have been partially successful in boring coal and soft rock.

The Siemens-Halske, Gardner, Adams-Dukee, and Dietz drills use a crank shaft driven by electric motor. The crank shaft carries a heavy flywheel and operates the cross-heads which strike the drill steel after being cushioned by springs. Such drills are heavy and cumbersome.

The Dulles-Baldwin and the Pneumelectric closely simulate the action of the two types of air drills, the piston and hammer drill, and thus get rid of a good many troubles of the earlier drills with positive acting hammers or cross-heads driven directly by the motor; but, in the opinion of the writer, certain fundamental difficulties remain, chief of which is that a small compressor plant is mounted in a position subject to excessive vibration, dampness, gas, and misuse, and is compelled to do very irregular work, the loads and resistances constantly varying. This is made manifest by the fact that much of the troubles are caused by the motors, the heaviest and most expensive parts of the machine. Both the drills referred to are much heavier and more costly than ordinary piston drills. For shaft work it has been demonstrated on the same contract that better work can be done by "Jap" drills than electric drills, with only a part of their weight and cost.

E. M., Weston on Electric Drills. In this connection the author quotes from a book by E. M. Weston, "Rock Drills, Design, Construction and Use, 1910"

"In attempting to compare electric with air drills, one can only say that, for mining purposes, there does not seem to be a large field open for them in competition with air drills under ordinary conditions. Their use might be recommended in places where power costs are very high and where high altitudes reduce the efficiency of compressor per unit of air cylinder area, where conditions are such that separate artificial ventilation, or efficient natural ventilation would have to be provided, regardless of the type of drilling machine employed.

"Dynamos and their insulation are on the surface guarded from jar or undue stresses of any kind, and from working in a dusty atmosphere. In mining they are mounted on a machine whose function is to produce jar and concussion. On the surface such machines are placed in the hands of skilled certified mechanics. Underground they must be left to the tender mercies of the man whose chief tools are the hammer and the drill.

"Air drills have one great advantage over electric drills in that they provide ventilation and cool the working place. Rapid development work in the Rand, for instance, would be impossible if the same air hose that worked the drill were not there to blow out the smoke after blasting."

Mr. Weston makes the following prediction, which has in great measure been borne out by the experience on this work:

"The development of the air-hammer drill has, I think, practically cut off the chance of any large use of electric drills. They are able to bore more rapidly, are simpler and lighter than any electric drill; while their consumption of power is smaller than that of a piston drill for the same work, in certain cases, the ratio of power developed at generator to power exerted on the bottom of the hole will almost bear comparison with that of the electric drill. The Temple electric-air drill should also limit the sphere of usefulness of any purely electric drill."

The above might have almost been written after the work on Contract 65 was well under way.

Hammer or Jap Drills for Shaft Sinking. When it was seen that the electric drills needed further development, small Ingersoll-Rand compressors, of 350 cubic feet free air per minute capacity, were installed at all shafts except 9 and 11 and driven by a 50-H.P. electric motor. This equipment furnished sufficient power to operate five or six plug drills and with them excellent progress was made in drilling and shaft sinking. The Manhattan schist is usually rather soft and easily drilled, and except where badly faulted is of fairly uniform consistency. In this rock the plug drills worked well, particularly good work being done by the Ingersoll-Rand F94 90-pound rotary "Jap," put upon the market in 1911, and used perhaps for the first time at these shafts. This drill has a mechanism revolved by the air which continuously rotates the socket in which the hollow steel is inserted. It has sufficient power to drill holes up to 8 feet in depth with a diameter large enough to take 1¼-inch dynamite.. With the Jap drills, at several of the shafts of this contract, a single round of holes, thirty-six holes, totaling 240 feet, was drilled in one shift of eight hours by six drill runners with only one nipper and three laborers to assist, no helpers being used. This gave a daily advance of about 5 feet. At Shaft 10, with Sullivan Japs, 37 feet have been made in one week, and 108 feet in one month. See also Contract 67, Shafts 19 and 20.

Comparison of Hammer and Piston Drills. In this connection it might be well to compare the hammer and piston drills. The hammer or "Jap" drill has all the advantage theoretically; it uses one-half the power of small piston drills. wears out much less steel, can be used by unskilled labor, or a skilled man can direct several; is much lighter and handier, and can be used in places where tripod piston drills are hard to get in and out. Lastly, they are much cheaper per unit, and a given number can be operated by a smaller compressor plant. Nevertheless, there are disadvantages under which the hammer drill operates. The hammer has to travel many times as fast as a piston to equal the blow of 60 pounds of reciprocating piston with drill steel. This causes crystallization of hammers, anvil blocks and steel, breaks the cutting edge of the bit, and develops weaknesses in welds. Hollow steel frequently breaks. It is said that fortunes have been spent in experimenting with special steel for hollow drills, and although great improvements have been made, there is still a great deal of breakage of the hollow steel by the users of hammer drills.

The advantages and disadvantages of Jap drills were well shown by the experience at several shafts of Contract 67. At Shafts 19 and 20 the rotating Ingersoll Jap drill was used to great advantage, drilling a complete round of 310 feet of holes in six hours with seven drills in the medium-hard Manhattan schist. Some trouble was caused by the breakage of steel and jamming in holes. At Shafts 22 and 24 Jap drills were installed and worked to good advantage on trimming holes in the hard grano-diorite there. This is a hard dark intrusive granite, which at Shaft 22 was quite uniform while at Shaft 24 it contained numerous seams. Trouble was experienced in drilling with Jap drills and much breakage of steel occurred. At Shafts 22 and 24 a combination of piston and Jap drills were used, and later piston drills alone.

Weston on Drill Efficiency. It is interesting to again quote from Weston, who admirably sums up the arguments on drill efficiency:

"The best drill is the most efficient. Mechanical efficiency is a different thing from practical efficiency. The theoretical engineer hankers after a tool which will give a percentage of efficiency of work done approaching that of the best triple-expansion pump in lifting water. His soul hankers after electrical transmission. He is grieved and indignant that any one should be content to use a tool driven by compressed air acting without expansion with an efficiency of only a few per cent of the force developed at the prime mover. He forgets this equation holds good in practice, P = practical efficiency; M = mechanical efficiency or power cost of operating drill; W = wages; C = cost of repairs or sharpening steel; S = standing interest and administration charges of undertaking; F = feet bored per unit of time. Then

$$P=\frac{F}{M+W+S+C}.$$

"When this equation is reduced to plain figures in actual cases, it is soon to be seen that M forms but a comparatively small part of the total figure. Boring speeds being equal the best machine is the one that will cost least for maintenance and consume the minimum of power. It must, however, be remembered that average boring speed is dependent on other factors than mere speed of reciprocation, or weight of blow. A machine might excel in these respects and yet break down so frequently as to waste much time underground in replacements and repairs. Or a drill might be so heavy and unhandy to set up, that the proportion of actual time available to perform work would be so small that a machine of slower maximum boring speed, that was light and handy, and could be kept at work for a greater proportion of working time would be preferable.

"No portable mechanical appliance of man as used by man has to do its work under such severe conditions as a rock drill.

"The average remedy for anything irregular in the working of the machine, due to drill bit sticking in the hole, is to take a hammer and hit hard and often and not to be too particular where.

"The modern type of rock drill may be considered one of the most wonderful products of inventive genius, when one realizes the manner in which difficulties have been overcome.

"To do this, however, has called for the best work that civilization can supply in selected materials and high-grade workmanship."

The shafts and tunnels of the City Aqueduct afforded a unique opportunity to demonstrate the qualities of many types of rock drills. More detailed information will be given in connection with the descriptions to follow.

Excavation of Shaft 6. Shaft 6 at Aqueduct Avenue and McCombs Road was sunk in Fordham gneiss, the first 70 feet breaking wild, due to mud seams and crushed rock. This was secured by concreting in the usual way, using Blaw shaft forms. The maximum weekly progress here during 1911 was 16 feet. Work at this shaft was started with the electric air drills and Fort Wayne, but these were superseded by Jap drills operated by a small Ingersoll-Rand compressor. In seven months this shaft was sunk 260 feet and 190 linear feet of lining placed.

Excavation of Shaft 7. Open Concrete Caisson. Shaft 7 at Sedgwick Avenue and 167th Street, close to the Harlem River, offered special problems of its own, particularly in the upper part. Before starting the chamber excavation it was necessary to rebuild

PLATE 209.—Contract 65. Shaft 7. Concrete Caisson Used to Reach Rock. This caisson was sunk in the open adjacent to Harlem R. R.

a 48-inch brick sewer and a 10-inch water main. After the chamber was excavated there remained 13 feet of sand and clay on the rock which it was supposed would be water bearing. To meet the difficulty it was decided to sink an open concrete caisson and seal it into the rock. The caisson shoe was set at elevation 0 and 13 feet of concrete cylinder built on it, and the sinking commenced. At elevation −6 feet a badly decomposed ledge was struck. Slow progress was made thereafter in sinking the caisson to elevation −24, at which time it was 24 feet long and 12 inches out of plumb. During the sinking of the caisson about 25 gallons of water per minute came in below the cutting edge. The excavation was then carried 10 feet below the cutting edge of the caisson and the outer lining placed. Thirteen feet below this sound rock was encountered at elevation −47 feet and more concrete lining placed. Between the caisson and elevation −47 feet the lining was reinforced with 1-inch horizontal bars. The shaft was subsequently sunk with the usual equipment of Ingersoll-Rand Jap drills and compressor, as before described.

Excavation of Shaft 8. Shaft 8 at Highbridge Park and 165th Street was started with Fort Wayne electric drills, but these were found unsuitable for the Manhattan schist encountered. A small Chicago pneumatic tool compressor was installed and sinking tried with small Jap drills. This was found to work so well that a larger Ingersoll-Rand compressor and Ingersoll-Rand rotary Jap drills as described were installed. With this equipment good progress has been made. A particularly well-shaped shaft has been obtained in the sound rock of this shaft, the Jap drills putting down the trimming holes close to the outer perimeter of the circular shaft. The method of excavation of Shaft 8 is shown on Plate 209, progress made on Plate 210. The maximum weekly progress in 1911 was 20 feet, the average 12 feet. This shaft was sunk 450 feet in seven months and 80 feet of concrete lining placed.

Excavation of Shaft 9. Shaft 9 was sunk with the Dulles-Baldwin electric drill previously described. The first 15 feet is in earth, the remainder in Manhattan schist of good quality to 100 feet. At this depth the shaft was concreted to the chamber, 14 feet internal diameter, using Blaw shaft forms of the usual type. Below 100 feet, 40 feet of bad ground was encountered with numerous slips extending the excavation as much as 9 feet outside the payment lines. This stretch was concreted in 20-foot lengths. Below the bad ground the rock is good and consistent

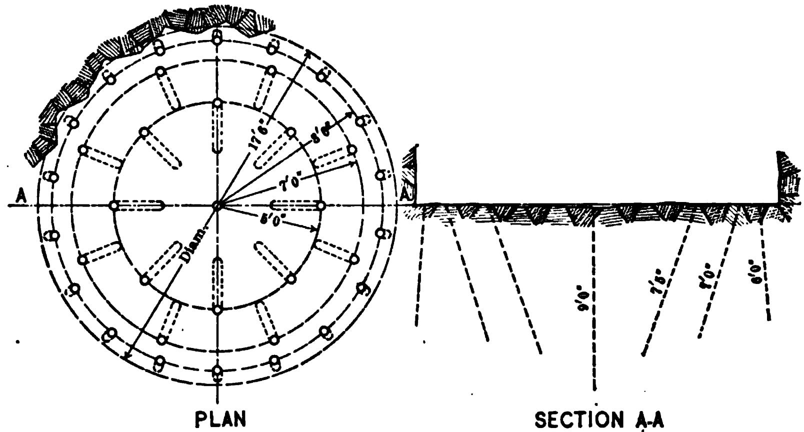


PLATE 210.—Contract 65. Arrangement of Drill Holes for Sinking Shaft 8.

	Holes Drilled.							Powder Used (lbs.).		Average Pull.	Cu. Yds. Brk'n Average.	Powder per Cu. Yd. Removed
	Number.			Depth.			Inclination.	Average per Hole.	Average Total.			
	Max.	Min.	Aver.	Max.	Min.	Aver.						
Cut...	9	7	8	9	7.5	7.7	1 vertical others 70°	4	32	5.0	15	2.1
Relief	10	8	9	....	....	7	73°	2½	22	5.0	30*	1.8
Line..	18	16	17	....	....	6	85°	2	34	5.0		
Total	37	....	34	....	....	227	....	.....	88	5.0	45	2.0

* Line holes shot before muck from relief round is entirely removed.

TYPICAL FORCE

Shift.	Time.	Class of Work.	Supt.	Ass't. Supt.	Timekeeper.	Shift Boss.	Electrician.	Mechanic.	Pipeman.	Hois Runner	Topman.	Drill Runner.	Dr. Rn. Helper	Nippers.	Muckers.	Blacksmith.	Bl'th Helper.	Watchman.	Compr. Eng'r.
3	12– 8	Drilling.......	..	1	..	1	1	1	..	1	4	4	..	..	..	1	2	1	1
1	8– 4	Mucking......	1	..	1	1	..	..	..	1	4	..	..	..	7	1	1	1	
2 {	4– 8	Drilling.......	1	..	..	1	..	1	..	1	4	4	..	..	..	..	..	1	1
	8–12	Mucking......	..	1	..	1	..	1	..	1	4	..	..	..	7	..	..	1	
3	12– 8	"	..	1	..	1	..	..	..	1	4	..	..	..	7	1	2	1	

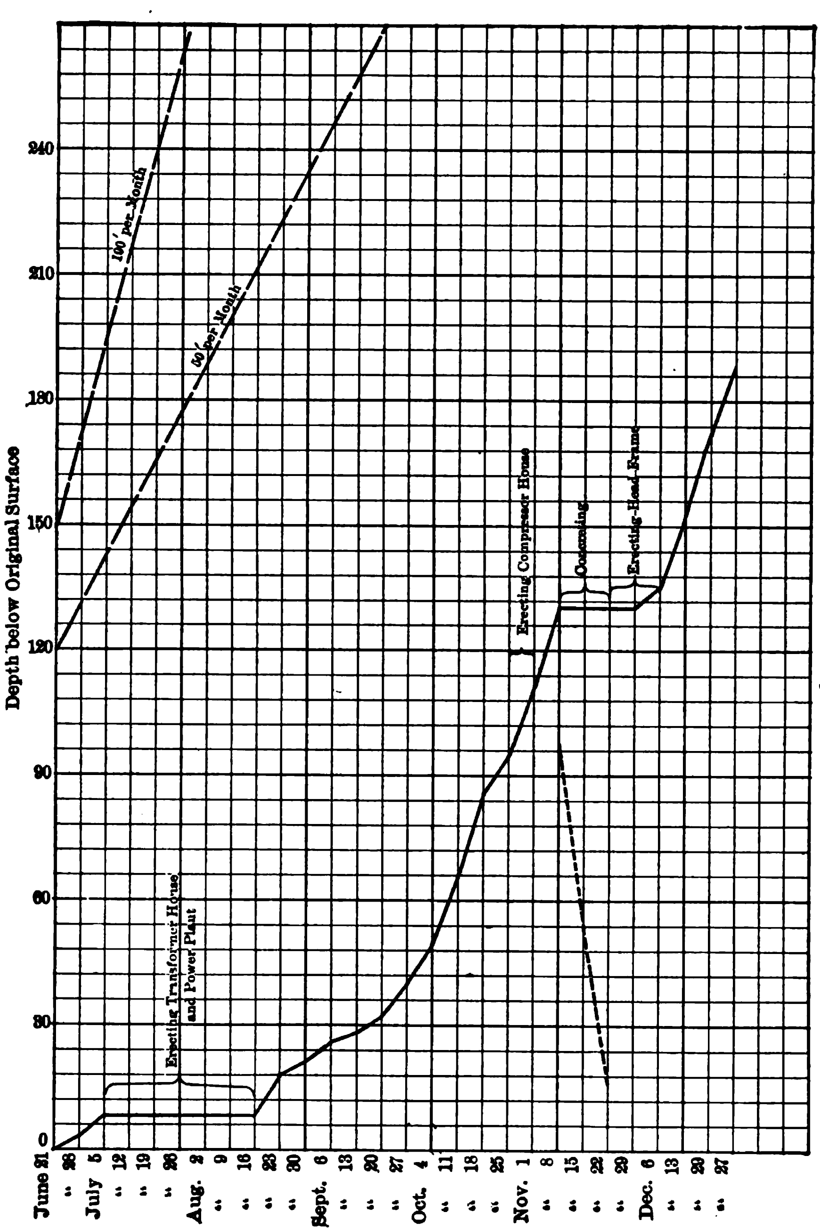


PLATE 211.—Contract 65. City Aqueduct Tunnel. Diagram of Progress at Shaft 8. Sunk Mostly with Jap Drills. Dotted line shows progress in placing concrete lining.

progress was made. The maximum weekly progress here was 20 feet during 1911, average 11 feet. Due to the constant remodeling of the Dulles-Baldwin electric drill, it was hard to keep a sufficient equipment of drills at work. The greatest trouble was with the motors, which have a tendency to overheat or burn out. Average progress at this shaft was, sinking, only 66 feet; sinking and lining, 49 feet monthly.

Excavation of Shaft 10. Shaft 10, at St. Nicholas Avenue and 135th Street, was outfitted with Pneumelectric drills which were used for about two months, after which a small Ingersoll-Rand compressor and an outfit of Ingersoll and Sullivan hammer drills were installed. Good progress was then made. The record for this shaft was 37 feet for a week, the average weekly progress being 18 feet. The rock here is a uniform hard Manhattan schist, and very dry, the maximum water inflow being 10 gallons per minute with 65 feet unlined. Very deep holes were drilled here with the Ingersoll-Rand rotary Jap drills, 6-foot cuts being pulled with holes nearly 8 feet long. The shaft was sunk 260 feet in four months and lined with 206 feet of concrete.

Excavation of Shaft 11. At Shaft 11, Morningside Park near 121st Street, an outfit of Pneumelectric drills was installed and the shaft sunk with them. At this shaft these electric drills were thoroughly tested and improved from time to time. The first drills were replaced by those of a later model, said to be more rugged and satisfactory. These drills are at a disadvantage in shaft sinking, as all the water used for cleaning the bits has to be raised to the top. The shaft is, however, very dry, so that the water can be readily bailed out. This feature, although adding complications to the handling of the machine, should be of a corresponding advantage in driving horizontal holes, particularly the so-called "dry-heading" holes.

During March there were twenty-two drills at the shaft, which was apparently being used as an experiment station for the Pneumelectric drill, consequently the operating charges for attendance was high. The drill has been greatly improved, but there was still trouble with the motors, which heated after several hours of continuous work. With this drill fair progress was made during 1911, the best weekly advance being 25 feet, the average 15 feet. The rock in the shaft is Manhattan schist with some pegmatite veins. The shaft is circular but somewhat larger than usual, as it is a drainage shaft. This shaft was sunk 240 feet in five months and lined with 175 feet of concrete.

PLATE 212.—Contract 65. City Aqueduct. Erection of steel headframe over shaft, which was sunk part way with derrick after which permanent plant with hoist and headframe was erected for remainder of shaft sinking, etc.

Shaft 12 was sunk with the Ingersoll-Rand hammer drills operated by 350-foot compressor to a depth of 230 feet in five months, during which time 120 feet of concrete lining was placed. The hammer drills were even used to good avdantage to drive the headings at the foot of the shaft being mounted on tripods for use in driving horizontal holes.

Electric Drills in Tunnels. After the shafts of this contract had reached tunnel grade, they were, with the exception of Shafts 7 and 12, equipped with outfits of electric drills, the Pneumelectric at Shafts 10 and 11, and Dulles-Baldwin at the others, and work with the latest models of these drills vigorously pushed. This work afforded a much better test of the electric drills than the shaft sinking. While sinking shafts drills are removed after each drilling and thus an opportunity is given to thoroughly overhaul and to replace defective parts on drills. The ventilation of shafts is also simple, although much time was lost at Shaft 11 waiting for smoke to clear after each shot. This, however, could be readily remedied by installing blowers and " smoke-jacks " or canvas hose reaching nearly to the bottom.

Difficulties with Ventilation while Using Electric Drills. As might be anticipated, the absence of air while drilling proved to be a serious disadvantage, the electric drills (particularly the Dulles-Baldwin) furnishing no air, but considerable quantities of heat and oily fumes from overheated motors and drills. Particularly when the drills were operating in the heading back of the muck piles the odor from the men and drills and the dusty atmosphere was almost overpowering. Where it was entirely practicable with air-operated drills to drill and shoot the heading in eight hours, this proved to be entirely impracticable with the electrics, due to their slower speed of drilling and frequent breakdowns and replacements of drills.

Final Results with Pneumelectric Drills. The final results of the use of Pneumelectric drills is summed as follows:

The first direct-current motors gave considerable trouble from water entering the casing and burning out the armatures. When replaced by alternating-current motors there was still trouble from overheating, necessitating the changing of one or two out of seven motors per shift. The power consumption per drill for horizontal holes was metered at 3 H.P., for vertical holes at 4 H.P. The drills cut horizontal holes at the rate of 4 feet per drill hour against 8.5 feet per drill hour for a 3¼-inch-piston air drill. The feet drilled per horse-power hour is 1.4 foot for the electric drill against 0.3

PLATE 213.—Shaft 10. City Tunnel, Catskill Aqueduct. Excavated material is raised at shaft and dumped from cars into bins over sidewalk and hauled away, mostly, in motor trucks.

foot per horse-power hour for air drill, showing that the electric drill had a mechanical efficiency of four times the air drill, but nevertheless could only drill one-half as fast as the air drill.

Principal Troubles of Pneumelectric Drills. The principal troubles which developed in the use of this drill were loss of pressure, breaking of dolly blocks, failure to rotate, stripping of gear, and breaking of piston rods.

Several of these defects were remedied by use of chrome vanadium steel for dolly blocks, improving of packing around piston rod, substitution of steel for cast iron, etc. This drill was very carefully made and in many respects was up to the standard of automobile machinery. The drill was finally after eight months of constant use and experiment discarded in favor of piston air drills, owing to the impossibility of securing adaquate ventilation without compressed air, especially while loading between shots and the impossibility of drilling two rounds a day in each heading.

Results Attained by Dulles-Baldwin Electric Drills. The Dulles-Baldwin drill appeared to work better while mounted on tripods for shaft work, as then its great weight was not objectionable, since the drills were readily handled by the hoisting engine and cable in shaft.

The drills weighed 435 pounds, although without motor, which was readily removed, it weighed 140 pounds less. While drilling heading it was difficult to secure proper mounting, and especially heavy columns, etc., were required. While starting a hole with the drill well back, the strain on the mounting was great and the vibration of drill tremendous. The drills consumed about 4 H.P. Over a period of five weeks when the drills were working at their best, they averaged about 5.3 feet per drill hour, but it took a full shift of eight hours with five drills to drill a heading, and usually one or two drills were disabled before the completion of the round. Usually many trips were made in taking drills and spare parts in and out of the heading during a drilling shift, and in order to allow this it was customary to completely muck out the headings before setting up drills. This led to very slow progress.

Principal Troubles of Dulles-Baldwin Drills. The principal sources of trouble with the Dulles-Baldwin drill were as follows:

Electrical: Grounding of motors, burning out of armatures, and short circuits in leads.

Mechanical: Stripping and breaking of gear teeth, shearing stud bolts holding gear to crank shaft, breaking guide shells, breaking cylinders, which was largely reduced by making cylinder and crank

Plate 214.—View Looking Down Shaft, Showing Timbering for Chamber to Rock and Concrete Lining in Rock Shaft Below. Steel shaft form—Blaw—in place at top.

end of one piece, breaking piston rings and rotation mechanism, loss of compression in cylinder and heating of drills. The loss of compression and failure of rotation mechanism were the chief causes of trouble.

Final Change from Electric to Piston Air Drills. The Pittsburgh Contracting Company, after giving the electric drills a most patient and persistent trial for over a year and sparing no cost, were convinced that it was impracticable to continue with them and installed individual compressors at all the shafts as fast as they could be brought and installed.

Use of Large Hammer or Jap Drills for Tunnel Driving. At Shafts 7 and 12 an effort was made to drive the tunnels with Ingersoll-Rand rotating Jap drills operated from small 350-foot compressors. The drills were mounted upon small tripods and fed with a feed screw much as an ordinary piston drill. Although these drills did excellent work, far outstripping the electrical drills in progress, they were found not equal to the task, making much dust and not exhausting sufficient air to materially benefit the men. These drills in turn were superseded by $3\frac{1}{4}$-inch piston drills, mostly Ingersoll-Rands.

Typical Plant at Shaft after Installing Compressors. When tunnel driving was resumed subsequent to the installation of piston air drills the typical plant at a shaft consisted of the following: Steel head frame and Lambert electrically driven hoist, these having been installed during the shaft sinking after the derricks were discontinued in the early part of the work. Lambert platform cages ($5' \times 8'$) operating balanced, were installed, and as the shafts are nearly all on side hills, they raised the two yard Koppel cars to the level of a steel trestle which led to bins at the roadside. The side-dumping cars fill the bins, which in turn are discharged into motor trucks of 5- to 6-ton capacity. These trucks were made by Garford, Saurer and Vulcan companies and gave very good service, hauling to fills at the foot of 129th Street, where the large steel skips hauled by the motors are dumped into the Hudson River by steel derricks. It is said that each truck could do the work of several teams. At three of the Shafts, 6, 7, and 8, the tunnel rock is crushed for concrete aggregate or used for other purposes. The usual compressor plant at each shaft consists of an Ingersoll-Rand compressor of 1000 cubic feet capacity and a smaller one used in shaft sinking of 600 feet capacity. A very large No. 8 or No. 9 or No. 10 Sturtevant blower, 3700 to 4800 feet capacity at 2 pounds initial pressure, is installed at each shaft, furnishing air through a 16-inch galvanized pipe down the shafts, branching into two 12-inch pipes into headings.

Tunnel Driving, Contract 65. After installing air compressors, the progress in tunnel driving was much improved, but as only two or three drilling shifts are used in each shaft but moderate progress is striven for. The rock at Shaft 6 is a hard Fordham gneiss, taking usually twelve hours to drill with two drilling shifts; the progress since permanent organization was effected is usually 40 feet per week per heading.

At Shaft 7 the tunnel under the Harlem Railroad penetrated the contact of Fordham gneiss and Inwood limestone which proved to be sound and dry; further along considerable water was encountered in a broken zone in the limestone. At the other shafts the rock is Manhattan schist of a good quality with the exception of stretches north of Shaft 10 and Shaft 12. The average weekly progress, since permanent organization was effected, in Manhattan schist, using three drilling shifts for two headings, was about 40 feet per week per heading during 1912. At Shaft 12 in a badly broken zone permanent steel bents consisting of straight I-beam cap and inclined legs supporting I-beam lagging was placed.

CHAPTER XX

CITY TUNNEL, MANHATTAN DIVISION

Contract 66

Work and Location. Contract 66 includes the construction of 4.8 miles of the city aqueduct pressure tunnel between 100th Street at Central Park and Fourth Avenue at Fourteenth Street. About three miles is to be 14 feet in finished diameter, one mile, 13 feet, the remainder 12 feet in diameter. Although the six shafts are located in the heart of the city, only one shaft site, that at Fiftieth Street, had to be condemned, five shafts being located in Central, Bryant, and Worth Monument parks.

The Shafts of Contract 66. The six shafts, numbered 13 to 18 inclusive, are to be equipped with risers connecting the tunnel with the distribution system. The shafts vary in depth between 205 feet and 250 feet, and are spaced from 2300 to 4500 feet apart. All the shafts are circular, 14 feet in finished diameter, except Shafts 13 and 18, which are irregular shafts containing two risers apiece and a section valve built in the tunnel, so that the water north or south can be cut off. In addition, each section valve shaft will have a permanent circular opening 9 feet in diameter through which access can be obtained to the tunnel after it is emptied of water. The section valve shafts are extremely complicated, as can be judged by examination of Plate 215.

Contract Prices. The contract was awarded to Grant Smith & Co. and Locher (later known as Smith, Hauser & Locher) in June, 1911, at a total contract price of $4,512,605. The unit prices are shown on pages 628 and 629.

Organization. The construction work of this contract has been under the charge of a member of the firm with considerable Western tunnel experience. He, however, has for most of the work employed shaft and tunnel men whose experience was gained in the East and particularly on previous work of the Catskill Aqueduct. Equipment and methods are accordingly Eastern.

The three shafts in Central Park were sunk by the Dravo Contracting Company, who furnished the organization and shaft equipment, while the main contractor furnished the power.

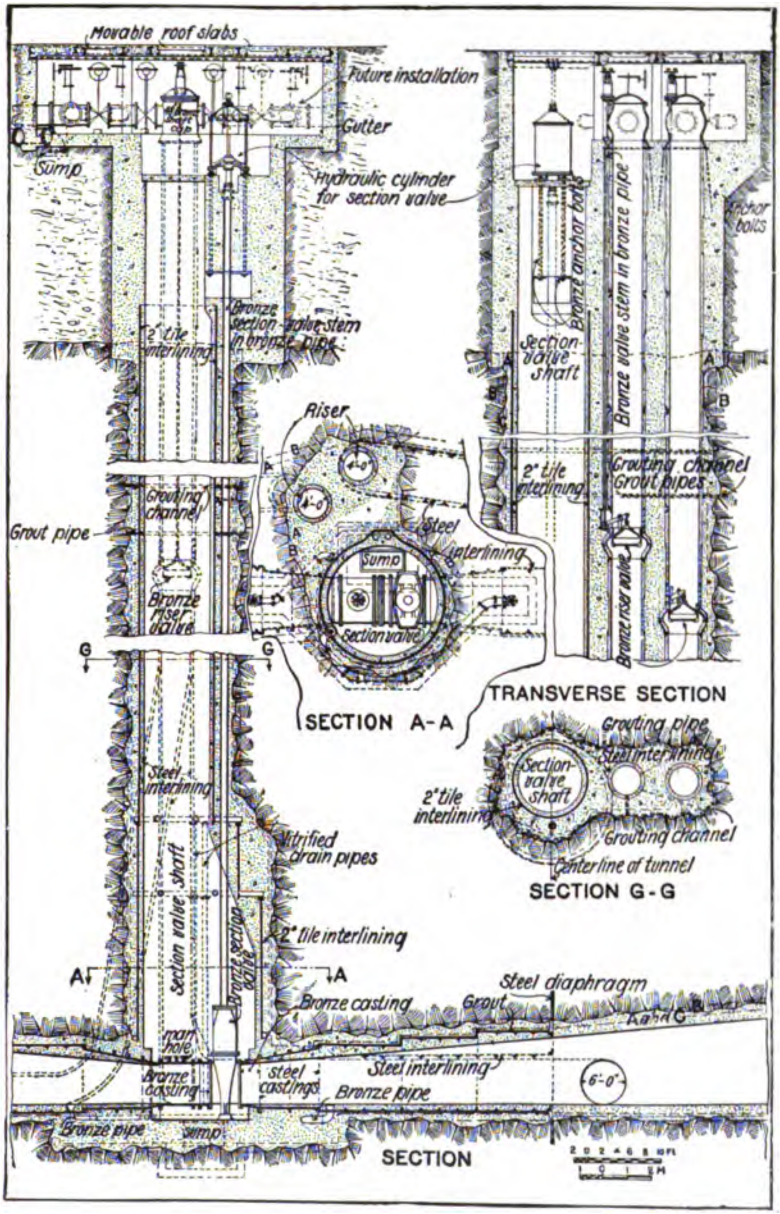


Plate 215.—Contract 66. Shafts 13 and 18. Details of Section Valve Shafts. Tunnel is cut off by large valve operated by hydraulic cylinder at top of shaft. Shaft serves also for access to tunnel.

BOARD OF WATER SUPPLY OF THE CITY OF NEW YORK

Contract 66, Manhattan Portion of the City Tunnel, Catskill Aqueduct

(Canvass of Bids opened May 16, 1911, at 11 A.M.)

Grant, Smith & Co., and Locher, Rome, N. Y.

Item.	Description.	Unit.	Quantity.	Price.	Amount.
1	Removing buildings	Lump sum	....	$1000.00	$1,000.00
2	Sinking Shaft 17 in earth	Linear foot	20	275.00	5,500.00
3	" 18 in earth	"	28	275.00	7,700.00
4	" 13 and portions of Shaft 18 in rock	"	405	330.00	133,650.00
5	Sinking all shafts and portions of shafts not in Items 2, 3, and 4	"	815	330.00	268,950.00
6	Excavation of tunnel and drift	Cubic yard	218,000	11.25	2,452,500.00
7	Additional trimming in shafts, tunnel, and drift	Square yard	1,100	5.00	5,500.00
8	Furnishing structural steel roof support	Pound	1,380,000	0.03	41,400.00
9	Erecting structural steel roof support	"	1,380,000	0.01½	20,700.00
10	Temporary timbering	M ft. B.M.	325	70.00	22,750.00
11	Pumping from shafts and tunnel during construction	Mil. ft. gal.	100,000	0.25	25,000.00
12	Drainage channels for shafts, tunnel, and drift	Lin.ft., sh., tu., dr.	24,465	2.00	48,930.00
13	Forms for outer lining of shafts	Lin.ft. of sh.	740	8.00	5,920.00
14	" outer and inner linings of section valve shafts	"	840	12.00	10,080.00
15	" lining of steel risers	Lin.ft. riser	1,525	5.00	7,625.00
16	" " tunnel and of drift at Shaft 16	Lin.ft. tu. and dr.	23,250	4.00	93,000.00
17	Concrete masonry in shafts	Cubic yard	9,100	10.00	91,000.00
18	" " tunnel and drift	"	85,000	7.50	637,500.00
19	Excess concrete masonry in shafts, tunnel, and drift	"	2,000	3.00	6,000.00
20	Brick masonry in shafts, tunnel, and drift	"	200	25.00	5,000.00
21	Dry packing in tunnel and drift	"	6,100	3.50	21,350.00
22	Drainage interlining in section valve shafts	Square foot	13,500	1.25	16,875.00
23	Steel interlining in risers	Pound	365,000	0.08	29,200.00
24	" " tunnel and at section valves	"	155,000	0.08	12,400.00
25	Cutting channels for water-stops	Square foot	1,500	2.00	3,000.00
26	Drilling 1½-inch or smaller holes in rock or masonry	Linear foot	1,000	0.40	400.00

27	Drilling $1\frac{3}{4}$-inch to $2\frac{1}{2}$-inch holes in rock or masonry	Linear foot	3,000	0.50	1,500.00
28	Steel pipe for grouting, etc.	"	30,000	0.30	9,000.00
29	Miscellaneous plant and equipment for grouting	Lump sum	....	5,000.00	5,000.00
30	High-pressure air compressors for grouting	Compressor	12	300.00	3,600.00
31	Air-stirring grouting machines	Machine	6	300.00	1,800.00
32	Mechanically stirring grouting machines	"	6	300.00	1,800.00
33	Grouting pads	Pad	40	80.00	3,200.00
34	Making connections of tank grouting machines to grout pipes	Connection	5,000	1.75	8,750.00
35	Setting grouting pads	Setting	2,000	1.00	2,000.00
36	Sand for grout	Ton	3,500	1.75	6,125.00
37	Mixing and placing grout	Cubic yard	5,000	10.00	50,000.00
38	Earth excavation in open cut	"	12,500	2.00	25,000.00
39	Rock excavation in open cut	"	5,000	4.00	20,000.00
40	Refilling and embanking	"	12,000	1.00	12,000.00
41	Timber and lumber	M. ft. B.M.	250	60.00	15,000.00
42	Concrete masonry in open cut	Cubic yard	2,000	8.00	16,000.00
43	Portland cement	Barrel	185,000	1.40	259,000.00
44	Steel for reinforcing concrete	Pound	100,000	0.05	5,000.00
45	Miscellaneous cast iron, wrought iron, and steel	"	125,000	0.07	8,750.00
46	Galvanizing	"	25,000	0.05	1,250.00
47	Caring for and setting metal-work furnished by the city	"	800,000	0.03	24,000.00
48	Cast-iron pipe and special pipe castings	Ton	60	100.00	6,000.00
49	Bronze pipe and miscellaneous bronze	Pound	600	1.00	600.00
50	Vitrified pipe, 18-inch and smaller	Linear foot	4,000	1.00	4,000.00
51	Dry rubble masonry and paving	Cubic yard	50	5.00	250.00
52	Rubble masonry and paving in mortar	"	150	7.00	1,050.00
53	Pavement	Square yard	5,000	5.00	25,000.00
54	Crushed stone and gravel	Cubic yard	400	2.50	1,000.00
55	Section office building	Lump sum	....	5000.00	5,000.00
56	Locker houses	"	....	8000.00	8,000.00
57	Restoration of parks	"	....	10000.00	10,000.00
	Total				$4,512,605.00

Bond required: $900,000. Time: 52 months.

Shaft Plant. Pending the delivery of the permanent plant installation at Shaft 14, three Sullivan electrically driven compressors of about 600 cubic feet of free air per minute were set up at Shaft 15 and connected with the permanent transmission lines for compressed air laid between the three Central Park shafts. A 12-inch screw-joint line leads from the main plant at Shaft 14 to Central Park West, branching there to two 8-inch lines to Shafts 13 and 15.

Sinking Shaft 13. Shaft 13 was sunk to the depth of about 100 feet with a stiff-leg derrick, after which a permanent head frame was erected and sinking resumed with a temporary electric hoist operating a non-rotating cable. This shaft, owing to its irregular shape and to the delay which would have ensued by waiting for the necessary risers, valve-stem pipes, etc., was timbered in the usual manner in stretches of from 50 to 100 feet. After a depth of about 125 feet was reached, a light pipe cross-head working on wire rope guide was installed in the hoisting compartment and the top of the shaft equipped with automatic door for safety.

Progress was necessarily slow and averaged while sinking about 14 feet per week. About 70 feet of timber were placed per week, during which time no excavation was in progress.

Grouting Water-bearing Seams. Shaft 13 proved to be the most difficult of all the shafts on the contract to sink, numerous slips and faults in the rock requiring timbering. In addition, three water-bearing seams were encountered, the highest being passed with no great trouble. The water from it was collected by a ring back of the shaft timbers and raised to the surface by a small horizontal air pump. The second seam at a depth of about 125 feet was encountered by the drill holes at one side of the shaft and yielded about 100 gallons of water per minute through a few holes. These holes were grouted under a pressure of about 250 pounds with neat cement, using a Caniff machine and Westinghouse booster without interrupting the sinking, a narrow bench being left from which the grouting was done. Later, this seam, after grouting, was uncovered, and proved to be a steep narrow pegmatite vein yielding very little water. Near the bottom of the shaft at a depth of over 200 feet another and very much larger seam was encountered, yielding so much water (about 100 gallons per minute) as to flood the shaft. Additional pumps were obtained and the holes grouted off as before, taking over 300 bags of neat cement grout at a pressure of about 300 pounds, the same equipment as before described being used.

Sinking Shaft 14. The best progress at any shaft of Contract 66 was made at Shaft 14, which was excavated through excellent

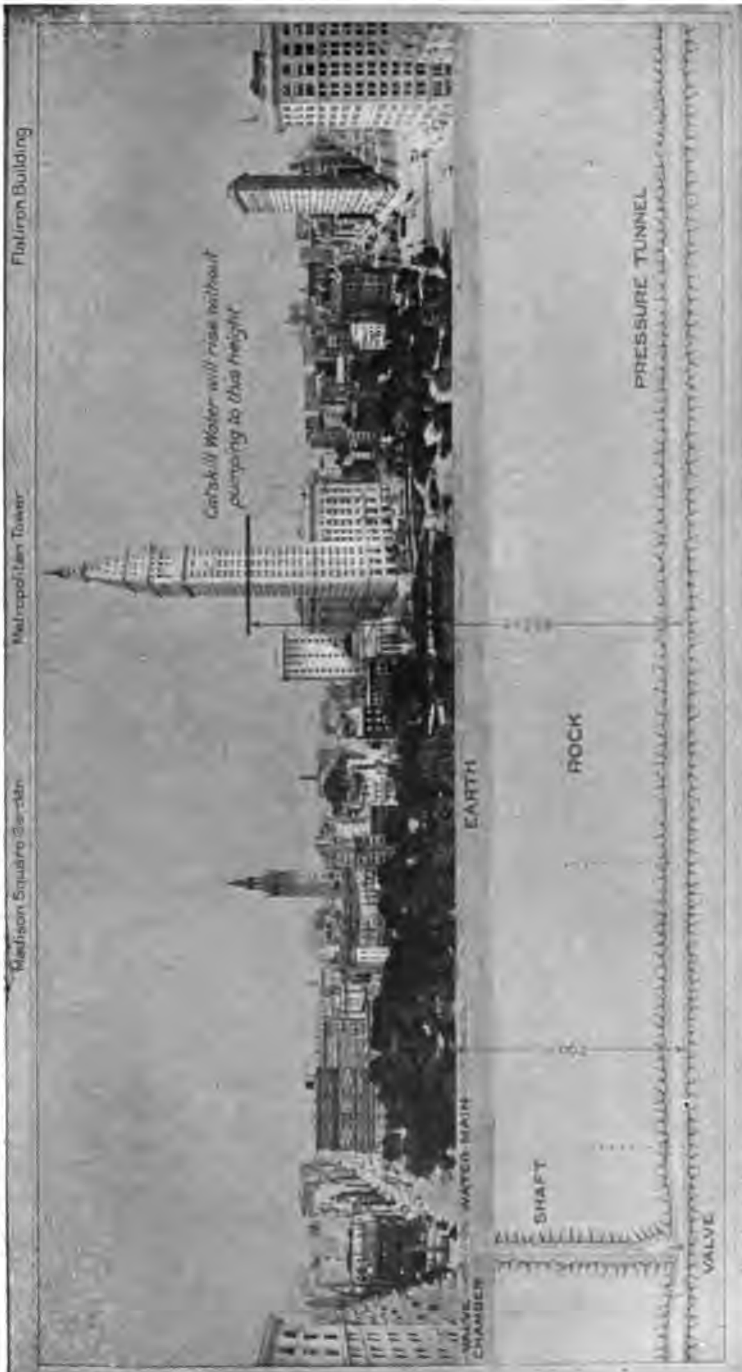


PLATE 216.—Pictorial Section of City Adjacent to Shaft 18 of the City Aqueduct. Shows position of pressure tunnel and hydraulic grade in reference to Metropolitan tower.

Manhattan schist of very uniform quality, and unusually free from slips and seams. This shaft, though located close to and between Central Park reservoir and a small natural lake, yielded practically no water. Shaft 14 was sunk by a skilled shaft-sinking organization in the usual manner. A uniform progress while sinking of about 5 feet per day was made, using three rounds of holes, 5 feet, 6 feet 9 inches and 8 feet in radius with a central hole to aid in breaking the cut. Holes were drilled with five large tripod piston drills 8 feet, 7 feet, and 6 feet deep, for the circular rows. The total number of holes were forty-one, aggregate length 272 feet; about 7 feet of hole per cubic yard and 3 pounds of 60 per cent dynamite were used. All the holes were usually drilled in one shift at night, and shot and the shaft mucked out in the two other shifts. The force at the shaft totaled about fifty men for the three shifts (average shift seventeen men) including five drill runners and helpers for one drilling shift, and nineteen muckers to the two mucking shifts. The best sustained progress for the contract was made at this shaft, 96 feet for three weeks, the average progress while sinking being 22 feet per week.

Detailed Tabulation of Method of Sinking Shaft 14.

Order of Shooting.	No. of Holes.	Depth of Holes.	Am't 60% Dyn. per Hole.	Total A'mt Dyn. Lbs.	Depth Pulled.	Cu. Yds. Pulled.	Dyn. per Cubic Yd.	No. Expl.	Total Lin. ft. Holes.	No. Drills
1	1	7	4.4	4.4	....	....	....	1	7	
2	5	8	3.5	17.5	....	....	....	5	40	
3	15	7	3.2	48.0	....	....	....	15	105	
4	20	6	2.2	44.0	....	....	....	20	120	
Total	41	.....	.....	113.9	5	38 ±	3 lbs.	41	272	5

Typical Force.	Superintendents.	Foremen.	Hoist Runner.	Signalman.	Muckers.	Laborers.	Blacksmith.	Blacksmith Helper.	Mechanic.	Drill Runner.	Drill-runner Helper.	Nipper.	Teamster.	Animals.	Engineman.	Nipper.	Watchman.
8 A.M. to 4 P.M. mucking....	1	1	1	1	9	1	1	1	1	...	...	1	3	6	..		
4 P.M. to 12 mid. mucking...	...	1	1	1	9	2	...	...	...	...	..	..	3	6	1		
12 mid. to 8 A.M. drilling....	1	1	1	1	...	...	...	...	...	5	5	..	..	..	..	1	1
Totals..................	2	3	3	3	18	3	1	1	1	5	5	1	6	12	1	1	1

Averages 1 day to drill and muck one round as per diagram.

PLANT USED. From Sept. 5, 1911, to Nov. 20, 1911, drills run by air supplied by power plant at Shaft 15. Three Sullivan compressors, 11″×14″×18″, supplying 300 cu.ft. of air per minute each.

From Nov. 20, 1911, to Dec. 6, 1911, air supplied from permanent plant at Shaft 14. Three No. WN2 Sullivan compressors, 26″×15½″×18″, run by electricity, and supplying 2100 cu.ft. per minute each. Only one compressor used.

1 Lidgerwood electric hoist, 40 H.P.; 1 General Electric motor, 40 H.P.; 1 Cameron No. 6 pump; 3 ½-yd. buckets; 1 derrick, mast 30′, boom 43′; 5 Ingersoll-Rand drills, No. F94 large, 3⅝″ cyl. 8″ str.; 2 Ingersoll-Rand drills, No. F94 small, 3¼″ cyl. 6″ str.; 1 blacksmith shop, and miscellaneous small tools; head frame in use from Nov. 4, 1911.

Concreting Shaft 14. The shaft was concreted in two stretches, using steel segmental forms built for the Dravo Contracting Company from Mr. Donaldson's design. They are similar to the Blaw shaft forms but are heavier with somewhat different details.

Central Power Plant. Before the Central Park shafts had reached grade, the permanent central plant at Shaft 14 was in service and furnished compressed air for all three shafts. This plant consists of three Sullivan cross-compound compressors, cylinders $26'' \times 15\frac{1}{2}'' \times 18''$, Class WN2, having a capacity of 2100 feet of free air per minute. They are driven by three Westinghouse 400-H.P., 6600-volt alternating-current motors supplied with current by the New York Edison Company. The water after cooling the compressor flows to a tank below ground from which it is raised to wooden cooling tanks above ground by a Cameron air pump, the tanks being at a sufficient elevation to force the water by gravity through the water jackets and intercooler of the compressors. Although the water after circulating for some time reaches about the boiling point, it keeps the cylinder and air from getting too hot, effecting a large saving in the water bills rendered previous to the installation of this system. Connection is also provided for the direct use of Croton water for cooling in case of failure of the above system to work. The compressors are supplied with a system of oil pipes through which the oil is supplied to the bearings from a central pump and filter below ground. The plant has given good service with few interruptions.

Shaft 15. Shaft 15 was sunk in a manner very similar to Shaft 14, but somewhat slower, the maximum week's progress being 32 feet, with an average of 21 feet. The shaft was the scene of a sad accident, caused by drilling into a portion of an unexploded charge of dynamite.

Shaft 16. Possession of the area at Shaft 16 on Fiftieth Street west of Sixth Avenue was not obtained until October, 1911, yet such good progress was made that in January, 1912, the heading was turned. This shaft illustrates the value of concrete lining, which was placed in two short stretches, 15 to 70 feet and 70 to 110 feet, to retain very blocky ground. After this the shaft was sunk to tunnel grade, depth 204 feet, and then concreted.

Concreting Shaft 16. A portable Smith self-charging mixer served by wheelbarrows loaded at the sand and stone piles dumped near by was used here. With this simple outfit, it was remarkable how quickly the Blaw shaft forms could be set up in the shaft, filled at the rate of 15 to 20 feet per day, taken out of the shaft and sinking resumed. At each concreting, hardly a week's interruption in the sinking was caused. It was found that the concrete lining could be started on the muck, after blasting the last cut in the shaft, without suffering any appreciable injury, except to the surface finish, when sinking and blasting were resumed. Cases are known where the concrete shaft lining has been placed on solid bottom and the shooting resumed a few days later without injuring the concrete other than marring the surface. It is said that concrete a few days old will resist shocks very well where older and hard-set concrete might crack.

Method of Sinking Shaft 16. Very good progress was made in sinking Shaft 16 which averaged 19 feet per week with 26 feet as a maximum. Although the shaft excavation is circular, about 17 feet diameter, the cut holes were drilled on the perimeter of a square about 5 feet on a side, 7 feet deep; the next on a square about 8 feet on a side; the third row of sixteen holes, 6.5 feet deep, was spaced on a circle about the C line. The reason given for the peculiar arrangement of holes is that it was desirable to take advantage of the nearly vertical stratification by drilling the holes parallel with the strike to enable the cut and side rounds to be pulled with few holes. This is borne out by the figures, which gave 4.44 feet of hole per cubic yard excavated against 4.90 to 6.10 feet per cubic yard for the other circular shafts. Despite this the shaft was driven close to line.

Sinking Shaft 17. Shaft 17, at Bryant Park and Forty-first Street, was started in August, 1911, and sunk to grade and headings turned December of the same year. Depth of shaft is 209 feet. The method of sinking was similar to that of Shaft 14, the average weekly progress being 17 feet, the best 24 feet. Rock at the bottom of the chamber was found to be badly disintegrated, requiring timber support, and was later concreted with an enlarged section reinforced by rods. The rock was generally sound below this with the exception of one ground-up zone which necessitated a stretch of about 30 feet of concrete to be placed above the depth of 140 feet.

Compressor Plant, Shaft 17. Excavation here was started with steam, which was soon replaced by compressed air, furnished by a permanent compressor of 2100 cubic feet per minute capacity. This compressor was one of the newest types of Ingersoll-Rand two-stage directly connected electrically driven compressors, size $25\frac{1}{4}'' \times 15\frac{1}{4}'' \times 21''$, Class PE. It is driven by a Crocker-Wheeler motor of 360 H.P., 6600 volts alternating current.

PLATE 217.—Contract 66. Shaft 17. Timbering of Chamber Over Shaft.

Compressors similar to these were also furnished for Shafts 16 and 18 and used for both the sinking and tunnel driving. They are remarkable for their quiet and smooth running, a very desirable feature where compressors have to be operated in crowded neighborhoods, as at these shafts. The single compressor at Shaft 17 supplied air for the shaft-sinking and tunnel-driving, running continuously for about sixteen months without a single delay. The compressors at shaft 16 or 18 to date have done about as well.

Electric Hoists. The shafts were sunk to a depth of 100 feet with derrick operated by small friction electric hoists. Later wooden head frames, 50 feet high, and large Lidgerwood single-drum direct-connected hoists were used. These hoists were operated by 90-H.P. D.C. motors, and, being equipped with carefully cut gears, made little noise. The cages were later operated by the same hoists.

Shaft Equipment. After the shafts reached tunnel grade they were concreted to near the level of the roof and two headings driven about 75 feet each way, and the cages installed. They are self-dumping cages and operate on wooden guides fastened to the head frame and concrete lining. The low Sanford-Day cars of 36 cubic feet capacity are equipped with end doors and are automatically dumped into the bins by a cam on the head frame. This cam engages rollers on the floor of the cage, which slides forward and tilts when above the bins, the cars being held by stirrups which automatically engage a pair of car wheels when hoisting of the cage from the bottom begins. These cars and the arrangements described work very well. Time is saved at the top of the shaft and the low car used is very convenient for loading.

Storage Battery Locomotives in Tunnel. Storage-battery locomotives, General Electric (3 to 5 tons), are being used for hauling in the tunnel, and are very successful, doing away with the dangerous and troublesome trolley wires. They have the great advantage of being able to run clear into the heading or to the face of the bench, and are more easily operated by switches than engines with trolleys. They have the disadvantage of requiring several hours for re-charging, which sometimes causes delay or necessitates extra locomotives or sets of batteries. As a rule charging can be done during waits at the shaft for blasting or other reasons. They are somewhat liable to get out of order due to battery troubles. The contractors express themselves as well pleased with their performance and state that their operating cost is low.

Ventilation. Ventilation is provided by Roots pressure blowers, which force air through a 10-inch galvanized iron pipe with crimped longitudinal joints; the transverse stove-pipe joints are bound with muslin dipped in coal tar and clamped with sheet-iron rings. At the end of the pipe, to reach the heading after shooting, a canvas pipe equipped with a 4-inch nozzle is unreeled, the air then being forced directly to the face of the heading to displace the smoke and gas. This system has been used with success, but the canvas pipe was little used.

Shaft 18. Shaft 18 is a section valve shaft similar to Shaft 13. It is located at Twenty-fourth Street at the intersection of Fifth Avenue and Broadway. Old maps indicate that a stream used to cross at this point, and the experience in sinking the upper portion of the shaft seems to prove this. This same stream gave considerable trouble in driving the Pennsylvania tunnel at Fifth Avenue and Thirty-third Street.

Steel Piling. After the valve chamber had been excavated to dimensions of $43' \times 38'$ to a depth of 13.8 feet, using heavy wooden sheeting and bracing, United States sheet-steel piling was placed to the irregular outline of the shaft in earth and driven by steam hammers into a gravelly wet ground with numerous boulders. The piling was guided by stout timber frames placed as the excavation deepened. No attempt was made to drive the separate piles much deeper than the bottom of the excavation, as boulders were liable to bend the sheeting or throw it out of line. This occurred at one place where a few piles were driven hard against a boulder, contrary to instructions. When rock was a reached at a depth of about 41 feet, or 29 feet below the chamber floor, it was found to be very soft and decomposed, necessitating driving the steel piling several feet into the ledge. This was accomplished by carefully excavating the rock below the sheet piling, which was driven down a few units at a time. When the piling was entirely driven, a very good job was obtained. About 40 gallons of water per minute came through the joints in the piling, but this gradually decreased through silting up of piling or by draining the ground. The rock was found to be rather soft mica schist to a depth of over 100 feet, requiring constant timbering. Fortunately it became much better near the bottom, where the shaft excavation was considerably enlarged.

Progress at Shaft 18. Considering the difficulties encountered at Shaft 18 very good work was accomplished. Between July 7 and December 20, 1911, the shaft was excavated to full depth,

PLATE 218.—Contract 66. Shaft 18. Steel Sheet Piling Used to Reach Rock through Water-bearing Gravel. Piling driven by steam hammer.

timbered, and a start made on the headings. The rock in the tunnels near the shaft is very interesting, consisting of beds of pure mica, pegmatite and talc veins, blocky mica schist, and even a well-defined vein of asbestos. Further along the rock is an ordinary mica schist.

Use of Explosives. As might be expected, the delivery, storage, handling, and firing of explosives in quantities necessary for good progress in the shafts and tunnels in the heart of Manhattan caused considerable anxiety on the part of the City authorities. The Fire Department of New York is in charge, through the Municipal Explosives Commission, whose ex-officio member is the Fire Commissioner, and the Bureau of Combustibles. The Municipal Explosives Commission is empowered by the State to enact regulations governing the use of all explosives, provided such regulations are not inconsistent with the State laws or regulations. The Bureau of Combustibles issues the licenses for and inspects the transporting, storing, and use of explosives, subject to the regulation of the Municipal Explosives Commission. The Fire Department was very reluctant to allow the storage of more than 100 pounds of dynamite at the shafts in congested neighborhoods, so that most of the shafts were sunk with 100-pound licenses. Later, 200- to 400-pound licenses were issued, the dynamite being stored at many shafts in first-class magazines, supplied with a hot-water heating system for thawing, and covered with sheet iron to make them bullet proof. All the powder used is 40 to 60 per cent dynamite, supplied by the Dupont Company, usually by two deliveries daily. The magazines are in charge of three shifts of licensed tenders and subject to very close inspection by the Board of Water Supply.

Underground Magazines. The Fire Department being very reluctant to grant licenses for the storage of 500 to 1000 pounds of dynamite, which is required for driving a pair of tunnels, the subject of storing powder at each shaft underground was investigated. It was found that underground magazines have been built in France and Germany and experiments there made; in one case 1000 pounds of dynamite was set off to test the construction. Usually it is considered objectionable to store dynamite below ground, owing to the liability of deterioration from moisture and danger to the underground workings and shaft in case of an explosion. But in most of the shafts the damage would be so great from the accidental explosion of a surface magazine, that it was determined to construct underground magazines at the tunnel grade. A large chamber was formed, entered from a

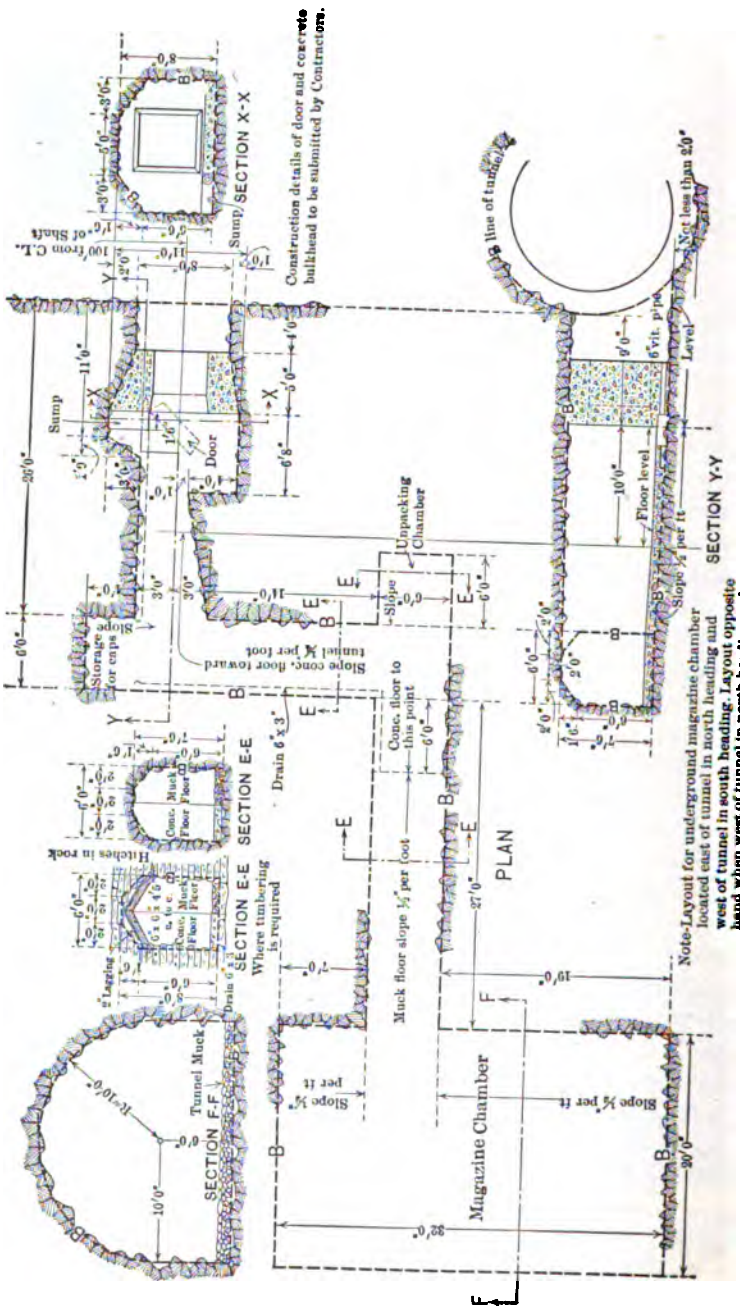


Plate 219.—Underground Magazine Chamber as Used for Storage of 1000 Pounds of Dynamite at Shafts of City Aqueduct Tunnels.

crooked drift 75 feet long, and the entrance to the drift closed by a very heavy automatic door to shut off gases in case of an explosion. A large conical wooden plug has also been used in Germany in place of a door, mounted so as to close the drift when driven by the gas generated by explosions of the magazine. It is estimated that the discharge of 1000 pounds of dynamite will give a pressure less than 100 pounds per square inch on the door. The magazine adopted is very similar to one used in Europe with reported success. Its construction is shown on Plate 219.

"Safety" Powders. The Municipal Explosives Commission has been very anxious to bar out dynamite in winter time, due to danger from improper thawing, and has investigated many so-called non-freezing "safety" powders. Two of these were tried on Contract 65 and one on Contracts 66 and 67, and found very inferior to dynamite. A low-freezing powder with the good properties of dynamite is something much needed, and lately such an explosive has been put on the market by the Dupont Company and used in the City since November, 1912, as by an ordinance of the Municipal Explosives Commission, nitroglycerine compounds subject to freezing are barred during the winter months. This compound, known as Dupont gelatin, is said to remain soft down to 0° to 10° F. It looks like a soft gelatin dynamite and so far has given very good satisfaction.

Bottom Heading. At Shaft 14 a good trial of the bottom heading method was given and a few hundred feet driven each way from the shaft, after which it became apparent that the expense of driving the lower half was so much that no possible saving in taking down the upper part could compensate for it. It was deemed impracticable to carry along a timber platform such as was used at Hunter's Brook tunnel. Horizontal holes were drilled around the perimeter of the upper half, which was shot down with light charges of dymanite. The supposed advantage of this method was not realized, the muck breaking up into large blocks which required considerable block holing and blasting. It was also found that considerable mucking at the face was necessary before the drill columns could be set up again. The rock at Shaft 14 was unusually sound, except in one place where cut by a dry clay seam. This gave some concern, as it seemed to weaken the flat roof over the bottom heading. It was impracticable to timber here, owing to the small clearances, but when the roof was taken down it no longer gave any concern, acting as a radial joint in a stone arch, illustrating the greater security of the arched over flat roof.

Comparison of Top and Bottom Headings. In general the experience on this contract was that a full section could be driven at much lower unit cost than any half section, the bench being carried along by the aid of a few extra drillers and muckers with no increased overhead expenses. This advantage cannot be obtained with the bottom head method without considerable cost for timber platforms, etc.

Tunneling along Strike of Rocks. The City aqueduct tunnels in Manhattan and The Bronx running north and south follow in general the strike of the almost vertical beds of gneiss and schist, making it difficult to obtain a well-driven tunnel, particularly in a circular tunnel, which tends to break with more or less parallel sides below the springing line. Seams and decomposed layers are troublesome, inasmuch as the tunnel tends to follow them for long distances. It is also reported that much dynamite was needed to blast the heading, the rock being reported as "rubbery." It is probable that more powder is needed to disrupt rock while working along rather than across the strike and that the mica schist is resilient and has a power to absorb shocks without being disrupted. Although 8-foot side-cut holes and 6-foot side rounds were usually used, the average advance was usually a little under 5 feet, the cut often requiring reloading, so that the average use of 60 per cent dynamite was 5 to 6 pounds per yard.

Progress in Tunnel Driving, Contract 66. On March 4, 1913, the excavation was completed, 23,000 feet of tunnel being driven in fifteen months, the first heading (Shaft 14 south) being turned December 6, 1911. The tunnels between Shafts 16 and 17 holed through October 2, 1912; between 13 and 14, February 19, 1913. The southern limit of the contract was reached February 25, 1913. This is a very good record, practically all the tunnel being completely excavated in one year. Very consistent progress was made in the 12 headings driven from the 6 shafts, the average progress from the time of installing cages and completing tunnel organization being about 46½ feet of completed tunnel per six-day week per heading. The best progress was made at Shaft 18, where the longest headings were driven, the average progress being about 53 feet per six-day week per heading. The slowest progress was made at Shaft 17, but here the most bad ground was encountered and the headings were shortest (1106 and 1650 feet). Considering the conditions, the average progress here, 33 feet per week, was good. The maximum progress was made at Shaft 18, where 152 feet of completed tunnel was excavated in the two headings in one week of six working days. The tunnels were excavated to about 18 feet in diameter from Shaft 13 to Shaft 17, between 17 and 18, to 17 feet, and south of 18 to 16 feet.

Four-drilling Shift Schedule. The tunnel schedule adopted was such as to lead to economical excavation at a fair speed, and no attempt was made at very rapid driving. At the shafts with long headings four drilling shifts were used in both tunnels; a complete round was drilled and shot in each eight-hour drilling shift, followed by an interval of four hours, which gave time for the tunnels to clear of smoke and allowed a margin for shooting, etc., in case special difficulties were met in drilling or shooting. Four drills on columns for heading and two on tripods for bench were usually employed, the bench being left about 50 feet back of face. A regular mucking gang consisted of 8 to 10 muckers and foreman. At times a split shift was employed in the four-hour interval between drilling and regular mucking shifts to help set up drills, muck, etc. With this arrangement two advances were usually made per day in each heading. A consistent effort was made to turn out all work inside the C line while driving the tunnel, leaving practically no excavation above track level to be taken out after holing through. The four-drilling shift method is given in detail in table, page 644.

Three-drilling Shift Schedule. The other schedule, used in the shorter tunnels and when the longer ones were in striking distance of each other, was to employ only three drilling shifts for each pair of tunnels at a shaft. The schedule for one tunnel was as described for the four-drilling shift method with, however, an eight-hour interval between drilling shifts, but the other tunnel had only one shift for that day. The next day two shifts would be alternated so as to keep the average progress the same in both tunnels. This method had the advantage of giving ample time every other day to completely muck out the tunnel, trim, lay tracks, dig ditches, scale heading and keep everything in first-class shape. With the four-drilling shift method, it was found more difficult to keep enough muckers to do the work. The cost per yard excavated to the contractors of the three-shift method was about the same as the four-shift method, but in long tunnels, or where there is ample labor and good superintendence, it is probable that the four-shift method is more economical, as the overhead charges remain the same for a greater progress. The average progress by the three-shift method was about 42 feet of completed tunnel per week per heading. For more detailed description of this

FOR ONE TUNNEL—INCLUDES WORK ON HEADING AND BENCH

Typical Force for 24 Hours, Heading and Bench.	Day Superintendent.	Night Superintendent.	Timekeeper.	Heading Boss.	Muck Boss.	Hoist Runner.	Enginemen.	Oiler.	Drillers.	Drillers' Helpers.	Muckers.	Electrician.	Blacksmith.	Blacksmith Helper.	Signalman.	Nipper.	Waterboy.	Dumpmen.	Pipemen.	Watchman.	Powderman.	Teamsters.	Animals.	Motorman.
Drilling, 2 A.M.–10 A.M.*				1					5	5						1								
Mucking, 12 M.–8 A.M.					1						20						1					1	3	1
Mucking down for columns and setting up, 10 A.M.–6 P.M.									1	1	2											4	12	
Mucking down for columns and setting up, 10 P.M.–6 A.M.									1	1	2											1		
Drilling, 2 P.M.–10 P.M.†				1					5	5						1								
Mucking, 12 M.–8 P.M.					1						20						1						3	1
	½	½	1	2	2	1½	3‡	3‡	12	12	44	1	1	1	3	2	2	3	2	3§	3§	6	18	2½¶

* Loading and shooting between 8 A.M. and 10. A.M.
† Loading and shooting between 8 P.M. and 10 P.M.
‡ Total force on compressor plant; supplies air to shafts 13, 14, 15.
§ For both tunnels.
¶ 1 motorman for both tunnels. during shooting.

method see description of tunnel driving at Shaft 19, Contract 67.

Close Driving of Tunnels. In this connection the method of obtaining well-driven tunnels is worthy of note. From plummet lamps, hung from center line plugs set by the engineer, the center line of tunnel was spotted on face of heading and the C line of excavation painted in red by heading boss or superintendent, aided in some cases by the engineers. This gave a very good guide for the systematic placing of holes. Preliminary sections were obtained by the "sunflower" every 20 feet and plotted on cross-section sheets. Every week copies of typical sections were sent the contractor for his information and on them attention was called to irregular breakage, low or high bottom, etc. The contractor also looked over the sections in the engineers' offices. Jap drills were used to drill the tight places, which were frequent along the springing line of roof due to vertical bedding of rock. In most of the tunnels a very fair approximation to the circular section was secured with little to be trimmed above the track level. The indications are that the tunnels will be found to average a little under the B or payment line established by the contract.

Timbering Used on Contract 66. In the driving of over 4 miles of tunnel on Contract 66, not more than 1600 feet of the roof required support. Isolated stretches of the Manhattan schist where badly broken by faulting were supported on 3-piece bents of temporary timber. A short stretch north of Shaft 13, and a much longer stretch north of Shaft 17, were supported by longitudinal I-beams supported on timber bents. At Shaft 13 the rock was badly faulted into blocks with soft talcy seams between. These blocks kept dropping out and the roof ran up several feet.

Bad Ground North of Shaft 17. At Shaft 17 the tunnel happened to follow exactly along the line of a longitudinal fault which cut the rock so that the tunnel roof was poorly supported at the right side wall by a ground-up layer of slippery talcose schist. The rock penetrated by the tunnel was dragged from a vertical to horizontal position and as it happened to be a rather hard quartzose schist was broken into small blocks. Shortly after the heading was shot, the material of the roof would run, requiring quick support, after which it was safe. It was feared that if temporary timbers were placed—and these would have been amply strong—difficulty would be found when they were removed previously to concreting.

Supporting Roof by Transverse Bents of Channels and Timbers. For a stretch of 75 feet improvised bents of wood and steel were used. These bents were composed of a 12-foot cap of two 10-inch channels clamped to a 8″×8″ timber core, and inclined legs of 10″×10″ timbers supported on wall plates of channels and timber built up like the cap, steel channels spanned from cap to cap and supporting the roof when dry packed. Where the roof broke high it was supported by I-beams, and channel lagging cribbed up from the cap. This system worked very well, the necessary steel being obtained out of stock on short notice. As the timber legs supporting the cap were set back of the C line in order to give sufficient concrete, the required section to be excavated was rather large. It was also felt that it would be safer not to concrete any large timber in pressure tunnel lining, so that the method of supporting roof was changed to a system similar to that used in bad ground on the Rondout siphon as described under Contract 12, but the method was modified and simplified to meet the conditions here.

Tunneling System Using Longitudinal I-beams as Crown-bars. A top heading of variable width was driven ahead as far as thought safe, in some cases only 5 to 10 feet ahead of the roof support, the main members of which were pairs of 9-inch I's bolted together with a timber between which also acted as a splice, or with bolts and pipe separators and steel splice plates. The I-beams were 12 feet long and broke joints. They were known as steel crown-bars and were used in a similar manner to the usual wooden crown-bars.

The crown-bars were continuously spliced longitudinally to the center line of tunnel, and at first blocked up close to roof on temporary cap and legs known as "horse heads." Usually three lines were placed 5 feet apart transversely, but at times when the heading broke wide an additional line was used. When the heading was particularly bad, it was driven narrow and two lines of crown-bars placed. The crown-bars alone, when blocked up to the roof, gave considerable support and usually the lagging could be placed several days later. About 50 to 100 feet back of the face the heading was widened out to receive wall plates and the regular 3-piece bents placed on them to support the temporary horse heads. Where the roof required support transverse 6-inch channel lagging in 5-foot lengths was placed transversely. When the bench was excavated the wall plates were readily supported on posts. The wall plates, composed of channels and 10-inch timber, were of great strength and readily spanned a gap at face of bench.

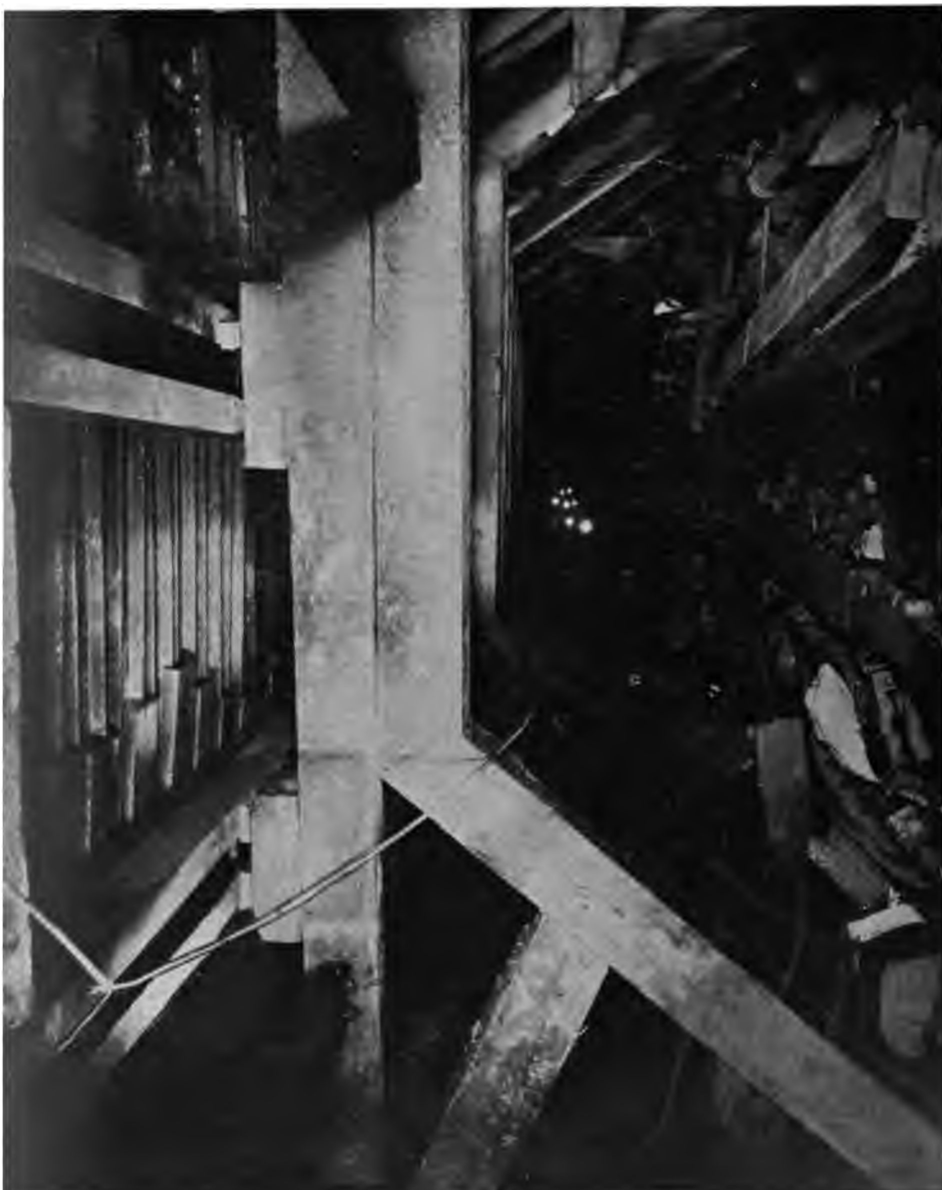


PLATE 220.—Contract 66. Tunneling in Heavy Broken Rock, Using Steel Crown-bars and Channel Lagging Over Temporary Timber Bents, as per Method Shown on Pl. 221.

Progress Made by Steel Crown-bar Method. The system proved to be of great flexibility, and readily adaptable to varying quality of rock. At times the crown-bars were kept within 5 feet of face, and were never shot out, although some temporary tim-

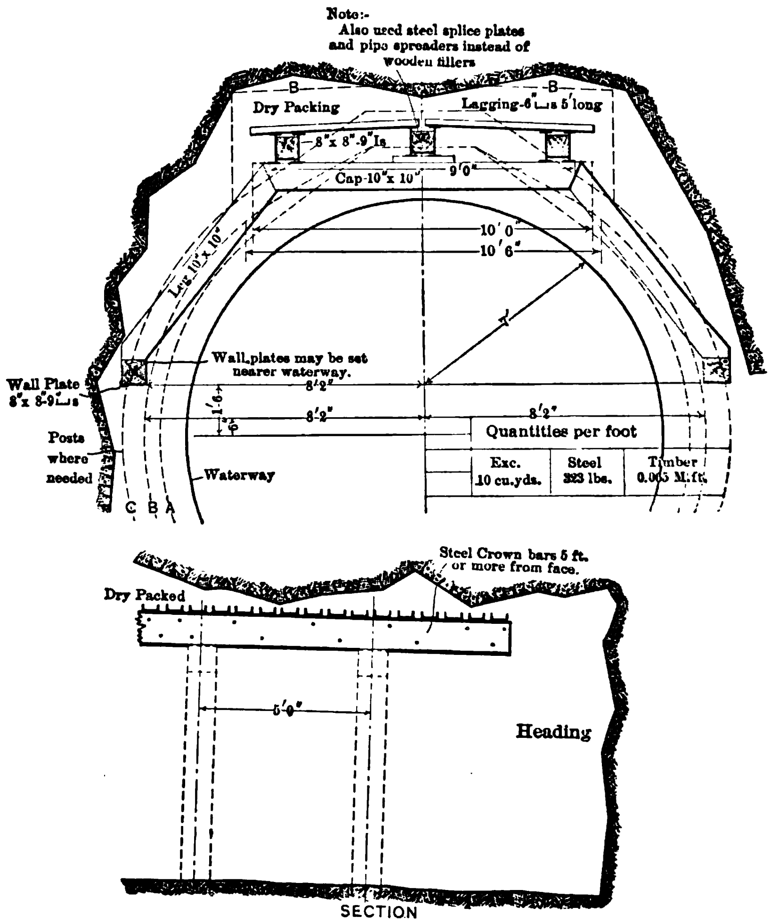


PLATE 221.—Contract 66. Shaft 17. Method of Supporting Poor Rock by Steel Crown-bars Over Temporary Wooden Bents.

bers were broken. A progress of 5 feet per day was regularly maintained in the heading, although the average progress was less to allow time to catch up back work. The system proved economical also, it being reported that the yardage cost of excavation did not run up above the other headings. In this connection, it is well to note that the payment lines on this contract are fixed at 13 inches outside any supporting steel, so that the section paid for ran 1.3 yards more per foot. About 300 feet were supported as described and although steel had to be ordered from time to time, it was taken from stock and readily adapted to the work, merely requiring to be cut to 5- or 12-foot lengths and punched with holes. This is a decided advantage of this system at times of steel shortage as compared to any regularly framed bent. It took about 14 weeks to pass the stretch of 351 feet requiring steel roof support.

Method of Concreting Arch below Roof Steel. The wall plates and timber bents supporting the longitudinal crown-bars were taken out in advance of the concreting of arch, so that in this section no wood was imbedded, except a few wall-plate posts, the concrete lining abutting on the rock walls or on dry packed steel lagging.

It was expected that the longitudinal I's would span a gap of about 20 feet, allowing three bents to be removed in advance of the concrete lining. The wall plates being placed 2 feet above springing line allowed the side walls to be placed without disturbing the timbering. To facilitate the placing of the arch, light steel bents of 9-inch I's were placed below the steel crown-bars and between the wooden bents at intervals of about 15 feet.

These bents were blocked to the roof beams so that the I-beam legs were bedded for a depth of about 2 feet into the concrete of the side walls, which after a few hours readily supported the bents.

The timbers were then removed from the concrete platform of side wall form so that later the arch form was moved into the same position as is usual with the method of using "trailing" arch and side-wall forms. The stretch of tunnel supported by steel was, owing to its large section, concreted in lengths of from 40 to 60 feet, and as was expected the removal of the timbers below the steel crown-bars did not delay the operation, this merely requiring small gangs to remove timbers between concreting or from-moving shifts.

Concrete Plant at Shaft 17. As soon as the tunnels between Shafts 16 and 17 holed through in October, 1912, the erection of the large concrete plant at Shaft 17 began simultaneously with the trimming of the tunnel each way from Shaft 17. The trimming was completed by the time the plant was ready for operation in November. This concrete plant is very complete, although erected on a very small area, formerly partly occupied by the compressor plant. It consists of a one-yard Chain-belt mixer, which is fed from two small overhead sand and gravel bins, and through a 12-inch pipe from the overhead cement shed. Alongside the small bins are two large bins of gravel and sand, 616 cubic yards and 360 cubic yards, extending to the ground. Over the large bins are the cement shed and operating machinery. Two vertical bucket conveyors, Stephens-Adamson Co., raise the sand and gravel from V-shaped hoppers below ground which are filled by auto trucks (4- to 6-yard Knox and Garfords) which dump directly into them through horizontal gratings at ground level. The vertical elevators are discharged by movable chutes directly into the small bins feeding the mixer, or more usually into the large bins, which can in turn through openings at the bottom be fed into the conveyors, so as to keep the small bins over mixer supplied at times when the trucks are not coming as fast as the concrete materials are used. The cement (Edison) is unloaded directly from the trucks to a bag elevator which delivers the bags to the cement shed above the bins. All the machinery in the plant is electrically operated.

Method of Concreting Tunnel. The mixer discharged through a flat chute directly into Koppel concrete cars on the cages. This was changed so that the cages were supported on landing dogs at platform level so that the cars can be run off and charged below the mixer from a concrete hopper holding two batches. This keeps things neater and expedites the loading. The concrete cars are made up into trains of three cars below and hauled by electric storage battery dinkies to the forms. The dinkies are very handy and simplify construction very much by doing away with the troublesome and dangerous trolley wires usually used. About the same methods of concreting as used on the Wallkill siphon and elsewhere is used, including Blaw forms, steel inclines, hoists on platforms, etc. It is expected that the tunnel will be rapidly concreted in 60-foot sections, using the "trailing form" method. Conditions for concreting are usually favorable, the tunnels usually being quite dry.

Expected Progress in Concreting. The speed of concreting tunnels and the methods of moving forms, etc., have now been so well standardized and are so reliable that it is confidently expected that by using the plant at Shaft 17, and a similar one at Shaft 14, the entire tunnel lining in the contract from Ninety-ninth Street to Fourteenth Street (over 23,000 feet) can be concreted in a few months. The largest haul of concrete in the tunnel will be about 7500 feet. It is expected that two storage battery dinkies will be sufficient at each plant, but to insure having charged locomotives on hand two others will be kept in reserve.

Contractors' Yard and Auto Trucks. The contractor secured from the Park Department an area at Eighty-first Street and Riverside Drive recently filled in by dumping tunnel muck hauled from the upper shaft. Scows of sand and gravel are delivered alongside the bulkhead and unloaded by a wide-gauge McMyler "Interstate" locomotive crane which stores the material on large stock piles back of the bulkhead and also fills charging bins from which the contractors' auto trucks are loaded. These trucks easily surmount a very steep grade on Seventy-ninth Street, where horse trucks have to be assisted by extra helping teams. The auto trucks are deemed to be more economical than horses for this service.

CONTRACT 67

Contract 67. Prices. Contract 67 was awarded to Holbrook, Cabot & Rollins Corp., George B. Fry, and T.B. Bryson, June, 1911, for a total contract price of $5,272,435. The items of the contract are given in the table on pages 652–4.

Work Included. The work to be done under this contract includes the concrete-lined tunnel extending from Union Square to Fourth Avenue, the Bowery, Delancey and Clinton streets, under the East River, and into Brooklyn as far as Fort Greene Park and Flatbush and Third avenues and Schermerhorn Street, where the two terminal shafts of the City Aqueduct are located. The northerly 7560 feet of tunnel will have an inside diameter of 12 feet and the remainder 11 feet. The six shafts excavated are spaced from 3800 to 5200 feet apart and vary in depth from 310 feet (Shaft 23) to 757 feet (Shaft 21), the latter depth including the sump at the foot of the shaft. Shaft 21 will be the deepest shaft on the line of the aqueduct with the exception of the shafts at the Hudson River. Shafts 19 and 22 will contain one 4-foot riser, Shaft 20 two 4-foot risers, the terminal shafts (Nos. 23 and 24) two 6-foot risers, and Shaft 21 will be the drainage shaft, containing also a 4-foot riser.

Features of Contract. The distinguishing feature of this contract is that compressed air was required to reach rock at all the shafts, the depth of rock below ground water varying from 36 to over 100 feet. Another feature is the small finished diameter of the tunnel, the step shafts, and the crooked alinement through the East Side

BOARD OF WATER SUPPLY OF THE CITY OF NEW YORK

CONTRACT 67, MANHATTAN-BROOKLYN PORTION OF THE CITY TUNNEL, CATSKILL AQUEDUCT

(Canvass of Bids opened May 16, 1911, at 11 A.M.)

HOLBROOK, CABOT & ROLLINS CORPORATION. 103 PARK AVENUE, NEW YORK CITY

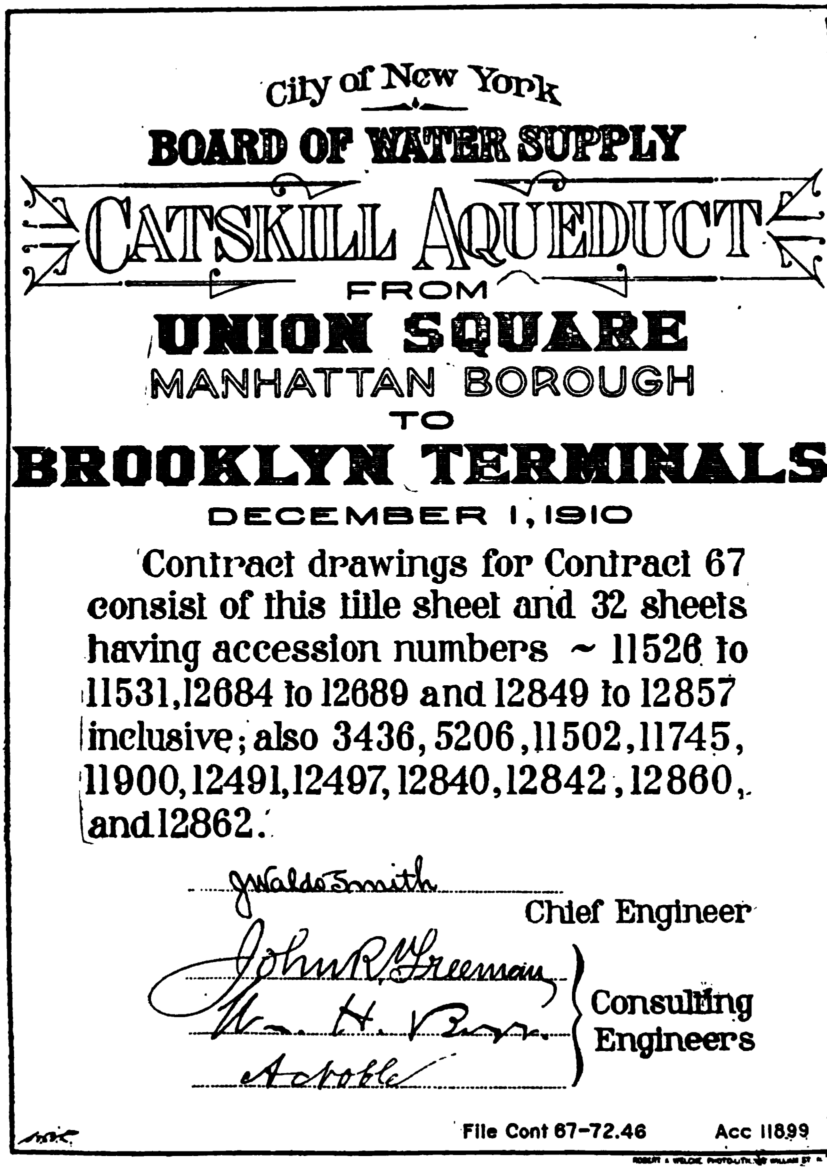
Item.	Description.	Unit.	Quantity.	Price.	Amount.
1	Removing buildings	Lump sum	....	$5000.00	$5,000.00
2	Excavation of Shaft 19 in earth	Linear foot	42	466.00	19,572.00
3	" Shaft 20 in earth	"	95	471.00	44,745.00
4	" Shaft 21 in earth	"	35	1082.00	37,870.00
5	" Shaft 22 in earth	"	93	456.00	42,408.00
6	" Shaft 23 in earth	"	120	735.00	88,200.00
7	" Shaft 24 in earth	"	100	614.00	61,400.00
8	" Shafts 19, 20, and 22 in rock	"	1,510	354.00	534,540.00
9	" Shaft 21 in rock	"	705	426.00	300,330.00
10	" upper portions of Shafts 23 and 24 in rock	"	215	423.00	90,945.00
11	" lower portion of Shafts 23 and 24 in rock	"	150	393.00	58,950.00
12	" tunnels and drifts	Cubic yard	157,000	10.70	1,679,900.00
13	Additional trimming in shafts, tunnels, and drifts	Square yard	1,500	4.00	6,000.00
14	Furnishing structural steel roof support	Pound	1,600,000	.04	64,000.00
15	Erecting structural steel roof support	"	1,600,000	.02½	40,000.00
16	Temporary timbering	M. ft. B.M.	290	70.00	20,300.00
17	Pumping from shafts and tunnels during construction	Mil. ft. gal.	500,000	.35	175,000.00
18	Drainage channels for shafts, tunnels, and drifts	Lin. ft. sh. tun. and dr.	24,350	2.50	60,875.00
19	Forms for outer lining of all shafts	Lin. ft. of sh.	2,900	7.50	21,750.00
20	" inner lining of drainage shaft	"	730	8.75	6,387.50
21	" lining risers	Lin. ft. riser	2,350	2.00	4,700.00

22	Forms for lining tunnels and drifts	Lin.ft. tun. & dr.	21,320	3.75	79,950.00
23	Concrete masonry in shafts	Cubic yard	26,000	10.85	282,100.00
24	" " tunnels and drifts	"	70,000	10.25	717,500.00
25	Excess concrete masonry in shafts, tunnels, and drifts	"	2,000	3.00	6,000.00
26	Brick masonry in shafts, tunnels, and drifts	"	200	20.00	4,000.00
27	Dry packing in tunnels and drift	"	6,500	2.50	16,250.00
28	Drainage interlining in drainage shaft	Square foot	36,500	.25	9,125.00
29	Steel interlining in risers	Pound	820,000	.07	57,400.00
30	" " and adjacent to drainage drift	"	70,000	.08	5,600.00
31	Cutting channels for water stops	Square foot	475	2.50	1,187.50
32	Drilling 1½-inch or smaller holes in rock or masonry	Linear foot	1,000	1.00	1,000.00
33	" 1¾-inch to 2½-inch holes in rock or masonry	"	3,000	2.50	7,500.00
34	Steel pipe for grouting, etc	"	40,000	.50	20,000.00
35	Miscellaneous plant and equipment for grouting	Lump sum	....	5000.00	5,000.00
36	High-pressure air-compressors for grouting	Compressor	10	300.00	3,000.00
37	Air-stirring grouting machines	Machine	5	300.00	1,500.00
38	Mechanically stirring grouting machines	"	5	350.00	1,750.00
39	Grouting pads	Pad	40	100.00	4,000.00
40	Making connections of tank grouting machines to grout pipes	Connection	8,000	1.50	12,000.00
41	Setting grouting pads	Setting	2,500	1.50	3,750.00
42	Sand for grout	Ton	4,000	2.00	8,000.00
43	Mixing and placing grout	Cubic yard	6,000	6.00	36,000.00
44	Excavation in open cut	"	11,500	3.50	40,250.00
45	Refilling and embanking	"	4,800	1.00	4,900.00
46	Timber and lumber	M. ft. B.M.	250	75.00	18,750.00
47	Concrete masonry in open cut	Cubic yard	3,200	12.00	38,400.00
48	Portland cement	Barrel	205,000	1.50	307,500.00
49	Steel for reinforcing concrete	Pound	1,000,000	.04½	45,000.00
50	Miscellaneous cast iron, wrought iron, and steel	"	450,000	.07	31,500.00

BOARD OF WATER SUPPLY OF THE CITY OF NEW YORK—*Continued*

Item.	Description.	Unit.	Quantity.	Price.	Amount.
51	Galvanizing	Pound	45,000	$.06	$2,700.00
52	Caring for and furnishing metal-work furnished by the city	"	930,000	.06	55,800.00
53	Cast-iron pipe and special pipe castings	Ton	100	80.00	8,000.00
54	Bronze pipe and miscellaneous bronze	Pound	5,000	.80	4,000.00
55	Vitrified pipe, 18-inch to 24-inch inclusive	Linear foot	500	2.50	1,250.00
56	" " 15-inch and smaller	"	1,200	1.25	1,500.00
57	Dry rubble masonry and paving	Cubic yard	100	5.00	500.00
58	Rubble masonry and paving in mortar	"	100	6.00	600.00
59	Pavement	Square yard	5,500	3.00	16,500.00
60	Crushed stone and gravel	Cubic yard	500	3.00	1,500.00
61	Reinforced concrete ladders	Linear foot	50	2.00	100.00
62	Section and locker houses	Lump sum	....	8000.00	8,000.00
63	Sinking casing and core drilling	Linear foot	8,000	5.00	40,000.00
64	Casing left in place	Pound	5,000	.06	300.00
	Totals				$5,272,435.00

Bond required: $700,000. Time: 54 months.



City of New York

BOARD OF WATER SUPPLY

CATSKILL AQUEDUCT

FROM

UNION SQUARE

MANHATTAN BOROUGH

TO

BROOKLYN TERMINALS

DECEMBER 1, 1910

Contract drawings for Contract 67 consist of this title sheet and 32 sheets having accession numbers ~ 11526 to 11531, 12684 to 12689 and 12849 to 12857 inclusive; also 3436, 5206, 11502, 11745, 11900, 12491, 12497, 12840, 12842, 12860, and 12862.

Chief Engineer

Consulting Engineers

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PLATE 222.—Title Page for Drawings of Contract 67. Representative of Contracts Signed by Chief and Consulting Engineers.

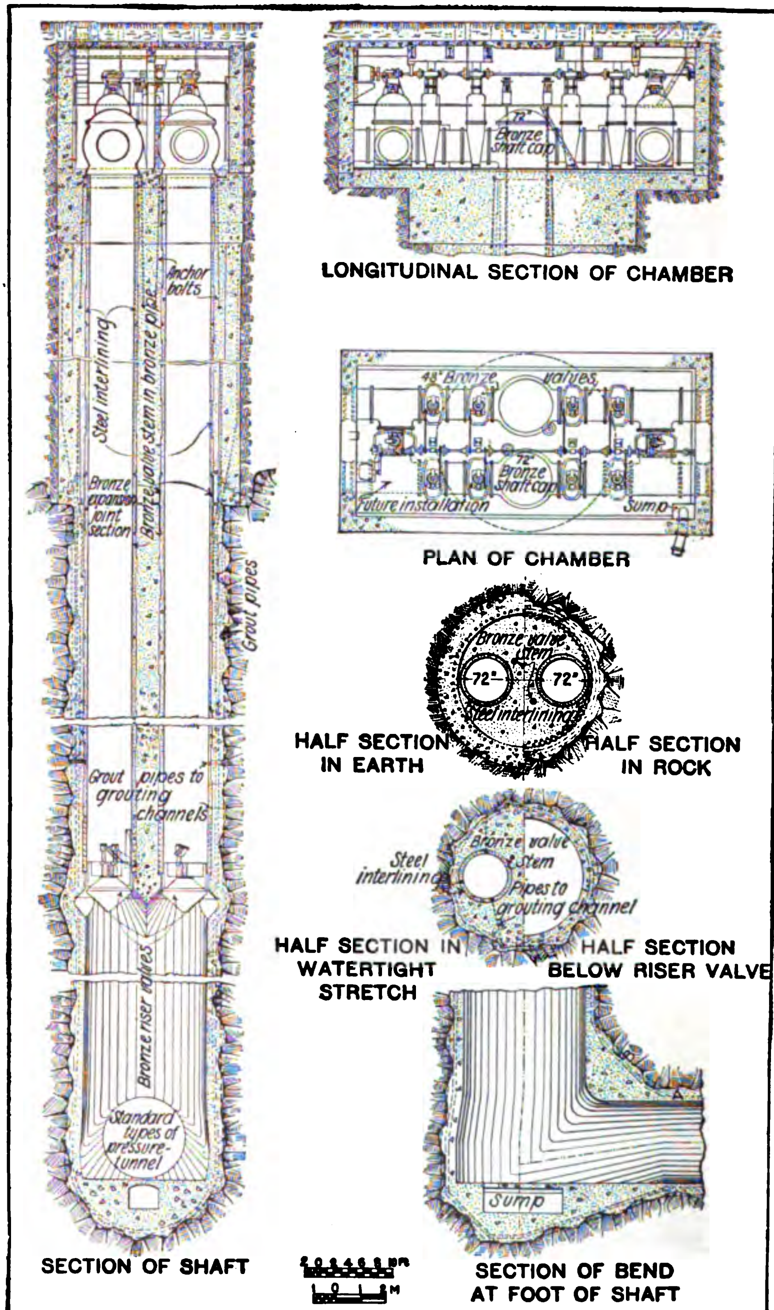


PLATE 223.—Contract 67. Shafts 23 and 24. Sections of Terminal Shafts, City Aqueduct, Showing Riser Pipes, Valves, etc.

streets, the latter being necessary to keep the tunnel under public property.

Change in Profile. The contractor proposed to eliminate the inclines (9.7 to 15 per cent) by sinking Shafts 19 and 22 to the deepest level (about − 664 feet) and driving the tunnel north from Shaft 19 at the upper level (about −181 feet) toward Shaft 18, and in the same manner driving the tunnel north of Shaft 22 toward Shaft 23 at the upper level (−288), making both step shafts. He estimated that by eliminating the inclines enough saving could be made in the driving of the tunnel to compensate for the expense of sinking Shaft 19, 181 feet and Shaft 22, 191 feet deeper. The City thereby will obtain the two level tunnels, minus the inclines, for the same cost as that on the original profile. The completed tunnel will all drain to Shaft 21, as originally designed. The City has accepted the modified profile (Plate 224) in order to eliminate the risk to life associated with tunnel construction on inclines.

Exploratory Work. Under items of this contract, the exploratory work left over from previous contracts was completed and definite

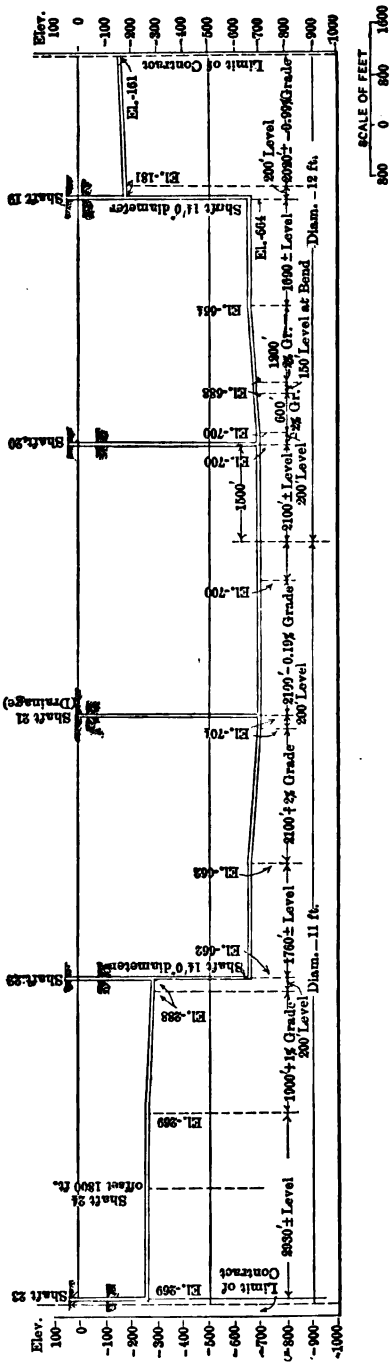


PLATE 224.—Contract 67. Revised Profile of City Tunnel. Inclines were eliminated by "step" or two-level shafts at either side of East River.

determination made of the rock through the East Side by diamond-drill borings, which gave all the information necessary to fix the final grades of the tunnel.

All core-drilling under this contract was done by machines and force furnished by Sprague & Henwood. For sinking casings, outfits known as "Minnesota Rigs" were employed. After rock was reached, diamond drills, either hydraulic or screw-feed, were employed to obtain cores to the depth desired. Ten old holes, which had been left in an incomplete condition by former contractors, were reoccupied, but the condition of the casing found in a few of these holes was such that they could not be deepened and new holes were substituted in addition to several new holes required to give additional information. Nineteen holes in all were occupied and a total depth of 6890 feet drilled. Nine of the holes reached a depth of over 700 feet, the deepest being hole No. 405, on Allen Street, which was 753 feet deep. These, in common with previous holes drilled in this neighborhood, were the deepest vertical holes drilled for the Board of Water Supply, with the exception of those in the Hudson River. A great deal of soft rock had to be penetrated in boring, resulting in the loss of one diamond bit and repeated attempts to get down. The work accomplished was very creditable, yielding a somewhat higher percentage of core than in holes drilled previously; also indicating that the quality of the rock at or near the tunnel grade was better than originally supposed, and that some deep points in the soft rock indicated on the contract drawings did not extend to depth shown. Two borings were driven close to the caisson at Shaft 23, to determine rock surface and length required for caisson. The type of drill rig used is shown on Plate 21.

Drilling of Hole No. 406. Unsuccessful Attempts. To illustrate the method and the difficulties of drilling deep holes in soft rock a detailed description of the boring of Hole No. 406 is here given. The East Side holes were probably among the most difficult.

Hole No. 406, near Hester and Essex streets, was started July 12, 1911. The hole had previously been drilled to 457 feet, and contained 161 feet of 6-inch, 164 feet of 4-inch, 208 feet of 2½-inch and 345 feet of 1½-inch casings.

When the hole was reoccupied a cave was found at depth 417 feet by washing. In order to get casing below this, the lowest casing was removed, the hole reamed down to 427 feet and 425 feet of 1½-inch casing put in. During the reaming the rods were stuck several times and once broke at 200 feet depth. Often after removing the rods, the hole would cave in for a distance of 10 to 30 feet, especially in depths 390 to 440 feet. At this depth it was estimated that only 75 per cent of the wash water returned to the surface; to keep the hole clear constant pumping, under pressure, was necessary. The ground below the 1½-inch casing continued to cave and it was further found impossible to either drive or pull out the casing, which finally broke at depth of 243 feet, leaving 182 feet in the hole.

The drillers finally succeeded in starting a new hole to one side from bottom of 2½-inch casing, getting it down to 366 feet, although constantly troubled with cavy walls, and occasionally by the top of the old 1½-inch left in the ground. This was blasted so as to chamber out hole at this point, after which the 2½-inch casing was entirely removed and the work continued by drilling and driving new 2½-inch casing, which broke and had to be again removed.

The 2½-inch casing was finally driven to 257 feet and blasting was done ahead of this to loosen the ground to enable further driving. The 2½-inch casing again broke 65 feet down and was removed. The old 4-inch casing was now removed and was found to have been broken and damaged by the blasting.

Final Success at Drilling Hole No. 406. New 4-inch casing was then put down to 219 feet by washing and driving. The drillers then put down 2½-inch casing to 230 feet by washing, chopping, and blasting. After August 11 good consistent progress was made, by drilling with diamond bit inside of 2-inch casing down to 462, with full return of the pump water and recovering 87 feet of 1½-inch core. Next 462 feet of 1½-inch casing was put in the hole, which was finished September 8th to depth of 736 feet, recovering 58 feet of ¾-inch core between levels 462 and 736 feet. To drive the casing the Minnesota rig was used, to drill rock a Sullivan hydraulic feed diamond drill.

Shaft Sites and their Use. At all the shaft sites, save at Shaft 19, substantial increases over the original contract area were obtained from the city authorities by the contractors, either by occupying large areas of bridge plaza or park space, or more usually by decking over the streets adjoining the shaft. The decking over of the street accomplishes a two-fold purpose: it gives the contractor more working room and lessens the interference of the work with traffic; derrick houses, etc., being supported overhead by heavy timber columns and I-beams. At Shaft 19 little increased area could be obtained, and the contractor, therefore, increased his working space by decking over the entire area, the upper deck projecting about 6 feet over the fence at the ground level. Although the ground area at the shaft is only about 5000 square feet, such good use has been made of it by very carefully planning each portion of the plant, driveways, muck bins, etc., that the plant is very efficient and work seems to be hampered only to a slight degree. The arrangement of the plant at Shaft 19 is well shown on Plate 225. It may be here noted that electric power alone makes it feasible to keep so much machinery in such a limited area, a small fraction of what would be occupied for the same purpose in open country.

Two Stages of Work. The work of Contract 67 passed through two stages. The first stage when the compressed-air work was done and the later stage of shaft sinking and tunnel driving. For the first work, temporary compressed-air plants were installed and the work was accomplished under the supervision of T. B. Bryson, a member of the contracting firm. These plants were obtained mainly by transfer from the Brooklyn Navy Yard, where similar work was drawing to a close. A typical plant consisted of a large upright boiler furnishing power for large stiff-legged derricks with booms ranging from 55 to 85 feet, a low-pressure compressor, and the usual outfit of steel shafting, locks, concrete mixing plant, etc.

Valve Chamber Excavation. The first work was to excavate the large valve chambers in open cut, using 4-inch sheeting and 12″×12″ wales and bracing. The valve chambers of Shafts 23 and 24 are of considerable size, 30′×60′ and 30 feet deep. No difficulty was met with in the excavating, the 4-inch sheeting being driven in single lengths, by hand and steam hammers or by pile drivers, operated by a derrick engine, in guides suspended from the boom. The last method was particularly satisfactory, as it could be readily operated by any derrick and is simple of construction. The material excavated was mainly sand of good quality and was later used for concrete, except in the Manhattan shafts, where the sand proved too fine and not worth saving.

Concrete Caissons. As soon as the valve chambers were constructed, the V-shaped steel shoe or cutting edge was bolted up at the bottom, and on it the concrete caisson was built with the aid of inside Blaw forms, of the type usually used in shafts, and outside steel-panel forms constructed by the Logan Iron Works. These caissons were entirely of concrete, reinforced by a double row of vertical and horizontal hoop-rods. The vertical rods are from 1 inch to $1\frac{3}{4}$ inch in size, connected by sleeves or turn-

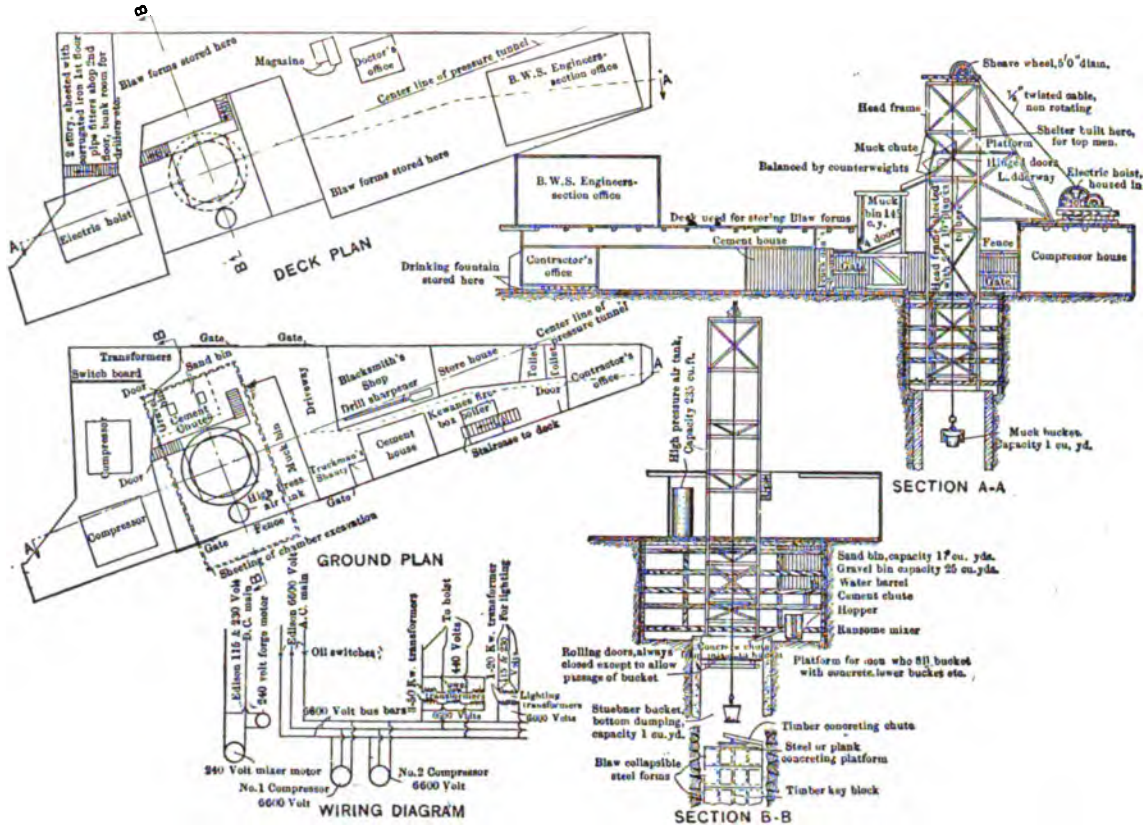


PLATE 225.—Contract 67. Plant Used for Shaft Sinking and Concreting in Restricted Area at Shaft 19. Intersection of Fourth and Third Avenues, Cooper Square. Same plant after installation of cages and tipples used for tunnel driving. Length of triangular area 140 feet, width 55 feet.

PLATE 226.—Contract 67. Shaft 19. Steel Headframe, Muck Bins, and Timber Deck at Shaft. Headframe boxed in for protection of men in shaft, and top protected by doors.

buckles, with laps for the lighter rods, the rods being upset and threaded for this purpose. The vertical rods terminate in turnbuckles inserted in holes through the steel shoe; they will later be connected up with the $1\frac{3}{4}$-inch rods, extended about 25 feet into the lining for rock shaft to insure caisson against overturning. All of the caissons, excepting those at Shafts 23 and 24, are 15 feet 4 inches inside diameter and 2 feet thick. Those at Shafts 23 and 24 are 18 feet inside diameter and 3 feet thick. The percentage of steel to concrete in each caisson varied from 2.2 to 3.4. Complete data of all circular caissons are given on table, pp. 668–9.

Concrete Plants for Caissons. At most of the shafts a simple but very efficient concrete plant was constructed by making use of the space available in the valve chambers. A Ransome mixer was set up at the bottom of the chamber, and fed through bins of sand and stone overhead, these bins being filled directly by trucks or by a derrick working in sand made available by excavating. The concrete was discharged in bottom-dumping buckets, which were raised and placed by the derrick. In order to insure watertightness during and subsequent to construction, an especially rich mixture was used, the cement factor varying from 1.7 to 2 barrels per yard; this, with Cow Bay gravel, gave a very dense concrete, which subsequently showed very little seepage.

Sinking Caissons to Ground-water Level. Sinking of the caissons alternated with concreting until the cutting edge reached ground water, after which the concrete deck was constructed from 6 to 7 feet above cutting edge and from 3 to $6\frac{1}{2}$ feet thick, depending upon the depth of the caisson. The decks were designed to take the load of wet sand with which the caissons were to be filled to give weight for sinking; and were suitably reinforced with steel rods embedded in the sides of the caissons or attached to rods so embedded. This gave a caisson entirely of reinforced concrete which proved to be very safe and satisfactory.

As soon as ground water was reached, in all cases caissons were built to their full height by the use of the steel forms, above referred to, from 45 feet (Shaft 19) to 123 feet (Shaft 23). Some of these caissons projected so far above the ground that difficulty was experienced in placing the final concrete with the derrick, although very long booms were used. Shaft 23 caisson projected 73 feet above ground, as shown on Plate 231.

Sinking of Caissons. An attempt was made to sink the caisson at Shaft 19 to rock without the use of compressed air. This was unsuccessful, although the highest rock here averages

PLATE 227.—Contract 67. View of Reinforcement of Concrete Caissons. Shows also steel outside and inside form and steel platform for placing concrete between forms.

only 20 feet below ground water. The material penetrated was a very fine sand which boiled up inside the caisson after it had been excavated 5 feet below ground water. A concrete deck 3 feet thick was then built and the caisson sunk to rock in a few days without difficulty. Before compressed-air men were employed, 3-foot steel shafting was carried above the top of caisson sufficiently, in most cases, to make room for the pig-iron platform. Two lines of shafting were used in all cases, except at Shaft 19, and supplied with Mattsen air locks. These locks are provided with the usual bottom and side doors moving on a track and supplied with rubber gaskets. The small cylindrical buckets are continuously operated in the shafting and are raised and lowered by a derrick operating a rope which passes through stuffing-boxes at the top of the lock and guided by a sheave-wheel held by a gooseneck on top of the lock. Usually one lock is used as a man-lock and the other for muck. At the first shaft sunk only one lock was provided with a hoist, the men climbing up a vertical ladder riveted to sides of the shaft. At the suggestion of the engineers, both locks were provided with hoists to save the men the exhaustion of a climb. This proved to be beneficial to the men and also expedited the sinking of the caissons, as both hoists could be used for mucking as well as for the men. After being fully equipped, the sinking of the shafts through the sand to the rock was a comparatively simple matter, the sand first removed being used to fill the interior of the caisson to add weight, after which it was removed by the derrick and carted to the dumps or stored for future use. A speed ranging up to 16 feet per day was made while sinking through sand and earth.

Schedule of Pay and Hours for Compressed-air Workers. The men employed on compressed-air work all belong to the Compressed Air and Foundation Workers' Union, under the following schedule:

Pressure, Lbs. per Sq.in.	Hours, Total.	Worked per Shift.	Wages per Shift.	
			Foreman.	Laborer or Sand Hog.
1 to 22	8	½ hour out for lunch	$5.00	$4.00
22 to 30	6	3 on; 2 or 3 off; 3 on	5.25	4.25
30 to 35	4	2 on; 4 off; 2 on	5.50	4.50
35 to 40	3	1½ on; 4½ off; 1½ on	5.75	4.75
40 to 45	2	1 on; 5 off; 1 on	6.00	5.00
Over 45	1 hr. 20 m.	As arranged	As arranged	

In addition, the wages are increased 50 cents per shift when doing concrete work.

As the number of hours per shift decreased, more shifts were taken on, so that the work was carried on continuously throughout the twenty-four hours, previous experience having shown that it is dangerous to have idle periods during caisson sinking.

Loading of Caissons for Sinking. A point was soon reached in the sinking of the caissons when the weight of concrete and sand filling was insufficient to force them down. Additional weight was then secured by loading up the platform at top of the caisson with pig iron, several hundred tons of this being required in most cases. Frictional resistance was found to vary from 300 pounds per square foot to over 1600 pounds per square foot. The material in New York City, composed of fine, micaceous sand, gave much lower frictional resistances than the Brooklyn coarse sand. The friction per square foot was found to be considerably higher for the caissons of larger diameter than for the smaller. At Shaft 24 the weight of the caisson was 1780 tons, but to reach rock an additional load of over 4000 tons was required.

Plumbing of Caissons. Every effort was made to sink the caissons plumb. While sinking, observations were taken on plumb-bobs in the working chamber, and on points at known elevations on the outside of the caisson. The best device was found to be a plumb-bob whose top was fastened in a pipe and concreted into the deck. This line was carefully compared with one suspended for the whole length of the caisson, so that foreman and inspectors merely had to measure the distance from the line to the concrete. The caissons at Shafts 19 and 20 were sunk nearly plumb, but those at the other two shafts were found to be out about 6 inches in 100 feet.

Sealing Caissons into Rock. The bulk of the work of sinking caissons is that in connection with sealing them into the rock. Although this character of work has probably been done where a caisson has been sunk for mine shafts, no records of the methods followed were available, and an original method had to be worked out for this contract. It was deemed dangerous to excavate outside the caisson and place concrete filling after sufficient penetration of rock had been obtained. The contractor proposed a method which was adopted for Shaft 19. This was to concrete a collar below the cutting edge and to a diameter $\frac{1}{4}$ inch larger than the outside of the caisson. While this was being done, the caisson, being heavy, was supported on wooden posts which were shot out, allowing the caisson to slip through the concrete collar, after which the cutting edge was concreted in and the space back of the shoe and around the concrete collar was grouted through pipes placed in the bench and through the walls of the caisson below the deck. This was found to be effective here, but there were indications that with higher heads there was danger of runs occurring between the concrete collar and the caisson after the first drop. A shorter and more effective method was originated by the engineers and subsequently used on all of the other circular caissons. After the rock had been excavated the required distance to allow for proper building of the concrete collar and bench, in which were placed grout pipes, the caisson was dropped onto a thick wad of oakum which was compressed by the cutting edge and formed an effective seal, made permanent by grouting the space back of the lower portion of caisson. The method of sealing is clearly shown on Plate 228. With sufficient pressure in the working chamber to keep out water, it was found that very good concrete work could be secured and that the set was very rapid in compressed air. All of the sealing operations were very successful, leakage at some of the shafts being almost imperceptible, with a maximum of from one to two gallons per minute after the air was drawn off. The rock at most of the shafts was found to be very irregular, and to make a proper seal it was necessary to go about 3 feet below the lowest point of the rock, and considerable rock excavation at the highest pressures was necessary. This work was accomplished with the aid of Jap drills and dynamite to blast inside the caissons, at which time it was necessary to remove all the men and shoot from the air lock. After the caisson was sufficiently ventilated by locking out the air containing the powder smoke, the men returned. The final lowering of the caisson after all the preparations for the seal had been made was readily accomplished by drawing down the air and allowing the caisson to settle hard on the oakum placed on the bench. To prevent the possibility of breaking the concrete bench, wooden posts capped by steel plates were concreted in so as to absorb the shock of the dropping. It is probable, however, that the concrete bench is of sufficient strength to withstand the shock without the wooden posts.

Comparative Caisson Data. Complete data obtained during the construction and sinking of the caissons of Contract 67 are given on pages 668 and 669.

Caisson at Shaft 20. A complete description of the sinking of the caisson at Shaft 20, Delancey and Eldridge streets, follows. This probably represents the most advanced construction and the

CONTRACT 67—COMPARATIVE

	No. 19.
Design and Construction:	
Outside diameter	19.33′
Inside diameter	15.33′
Total length including shoe	45.00′
″ excluding shoe	42.75′
Thickness of deck	3.0′
Ht. of working chamber (cutting edge to bottom of deck)	6.25′
Length of shafting (man)	54.00′
″ ″ (muck)	54.00′
Mattsen locks (man)	Wt. 6000 lbs.; dia. 3.33′
″ (muck	Wt. 6000 lbs.· dia. 3.33′
Air inlet pipe	3-inch
Grout pipes above shoe	16
Concrete proportions (dist. taken from cutting edge)	1½–2–4
″ ″ ″ ″	....
″ ″ ″ ″	....
Cement factor	1.91
Time elapsed setting shoe to first concrete, days	9
″ of concreting, 8-hour shifts	12 (Sept. 15–27, '11)
Sinking Caisson:	
Lowered without compressed air, feet	21.7
Hours per shift in compressed air	8 6 4 3 2
Sand excavation, number of shifts	5
″ feet sunk in compressed air	11
Rock excavation, number of shifts	51
″ feet sunk in compressed air	14.2
Maximum depth in rock	14.2′
Minimum depth in rock	5.0′
Maximum air pressure used	17 lbs.
Weight of caisson	460 tons
″ ″ Maximum load	700 tons
Friction test No. 1, penetration and resistance	300 to 400 lbs. sq.ft.
″ No. 2, ″ ″	....
″ No. 3, ″ ″	....
″ No. 4, ″ ″	....
″ No. 5, ″ ″	....
Seal:	
Height of collar	1.5′
″ bench	0.8′
Average thickness of collar and bench	0.7′–1.7′
Leakage after constructing seal and removing air	1 gal. per hour
Grout pipes in collar	6
Constructing collar, lowering caisson and grouting hours	64
Time elapsed from placing shoe to removal of air	Sept. 6 to Oct. 30, '11
Elevations:	
Original surface	43.7
Bottom of chamber	20.7±
Top of caisson	19.6
Cutting edge	−25.4
Ground water	+ 4.0
Highest rock	−12.0
Lowest rock	−21.2
Rock excavation under air to	−26.2
Payment quantities:	
Grout connections	15
Yards of grout	8.2

CAISSON DATA

Shaft.			
No. 20.	No. 22.	No. 23.	No. 24.
19.33′	19.33′	24.0′	24.0′
15.33′	15.33′	18.0′	18.0′
105.3′	100.0′	123.0′	105.6′
103.05′	97.85′	119.75′	102.06′
5.5′	5.0′	8.0′	6.0′
7.25′	6.0′	7.0′	6.25′
120.00′	120.0′	144.0′	120.0′
120.00′	126.0′	150.0′	120.0′
Wt. 6000 lbs. dia. 3.33′	Wt. 6000 lbs. dia. 3.33′	Wt. 10,000 lbs. dia. 4.4′	Wt. 6000 lbs. dia. 3.33′
Wt. 6000 lbs. dia. 3.33′	Wt. 10,000 lbs. dia. 4.4′	Wt. 10,000 lbs. dia. 4.4′	Wt. 10,000 lbs. dia.4.4′
3-inch	3-inch	3-inch	3-inch
16	24	18	18
1½–2–4	0 to 13′ 1½–2–4	0 to 73.5′ 1½–2–4	0′ to 21′ 1½–2–4
....	13 to 51′ 1½–2–4	73.5 to 94.0′ 1½–2–4	21′ to 43′ 1½–2–4
....	51 to 100.1′ 1–2–4	94 to 123′ 1–2–4	43 to 105.25′ 1–2–4
1.97	1.70	1.86	1.72
10	21	6	16
37 (Oct. 6–Nov. 12,'11)	47 (Sept. 8–Oct. 5, '11)	66(Nov.16–Dec.23,'11)	57 (Sept. 9–Oct. 12,'11)
11.2	33.0	19.0	27.5
8 6 4 3 2	8 6 4 3 2	8 6 4 3 2	8 6 4 3 2
18 5 12	16	14 4 5 7	22 6
50.6 18.4 8	50.3	70 15 9 11	46.3 13.2
91 28	61	13 156	66
12.7 21	13.7	3.5 10.5	10.0
14.8′	12.8′	12.2	8.7′
5.9′	1.1′	2.1	2.4′
39 lbs.	28 lbs.	46 lbs.	29.5 lbs.
1050 tons	978.3 tons	2323 tons	1780.0 tons
2100 tons	2470.3 tons	4612 tons	4046.0 tons
630 lbs.sq.ft.	77 ft. 736 lbs. sq.ft.	45 ft. 1411 lbs. sq.ft.	49 ft. 1685 lbs. sq.ft.
....	81 " 630 "	65 " 1450 "	52 " 1502 "
....	93 " 728 "	77 " 1217 "	73 " 1156 "
....	95 " 751 "	86 " 1202 "	79 " 1101 "
....	....	116 " 872 "	93.5 ft. 945 "
2.0′	2.0′	1.5′	2.0′
1.0′	1.0′	1.5′	1.6′
0.8′–1.8′	0.6′–1.6′	0.6′–1.5′	0.7′–1.7′
¼ gal. per hour	¼ gal. per min. (seam in rock)	7.2 gal. per min.	3.4 gal. per min. (seam in rock)
6	10	8	11
35	51	51.5	51
Sept. 26–Dec. 23, '11	Aug. 17–Nov. 4, '11	Nov. 10–Feb. 19, '12	Aug. 23–Nov. 16, '11
40.2	53.4	40.7	51.7
17.2±	29.5	10.1	21.0
20.5	33.5	15.6	31.2
−84.8	−66.5	−107.5	−74.4
+6.0	− 3.5	− 6.5	− 5.0
−71.0	−53.8	− 95.3	−66.0
−79.9	−65.5 pocket	−105.4	−72.3
−85.8	−67.5	−109.0	−76.0
6	27	20	17
16.8	3.4	11.8	3.3

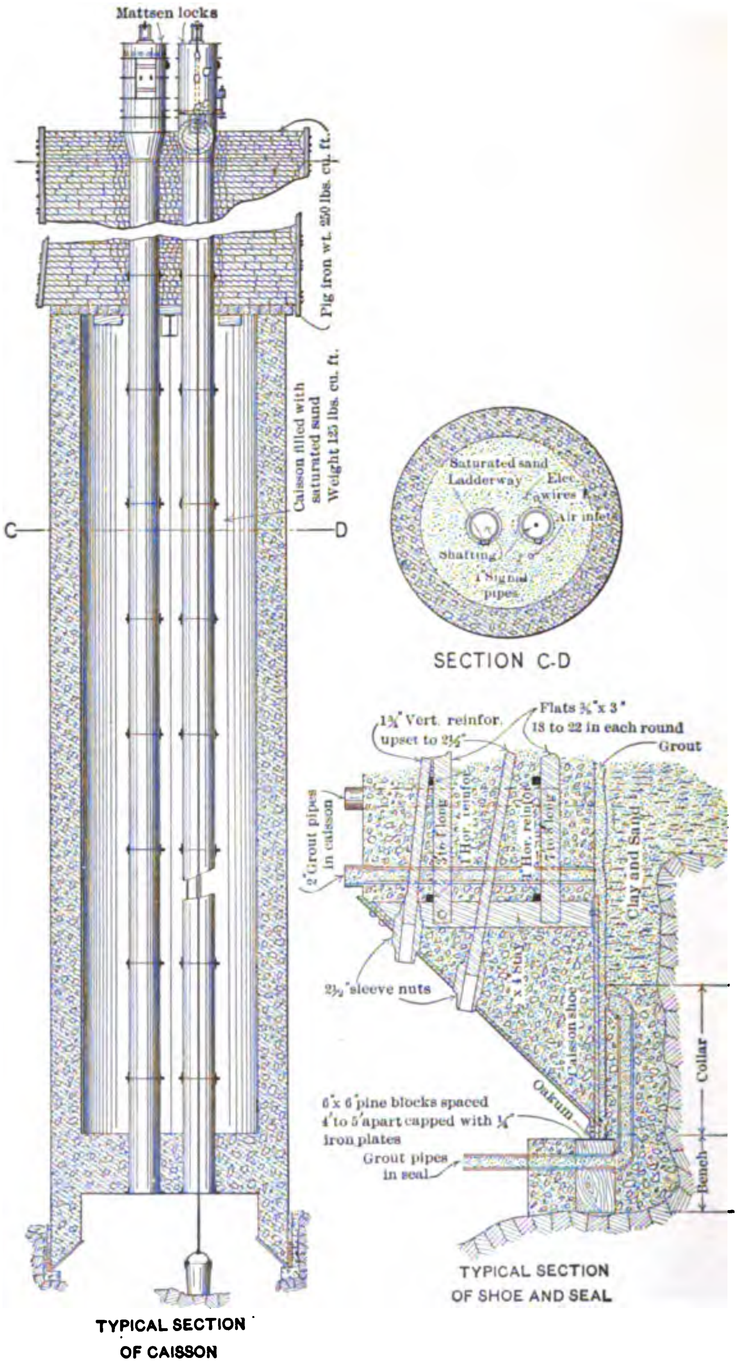


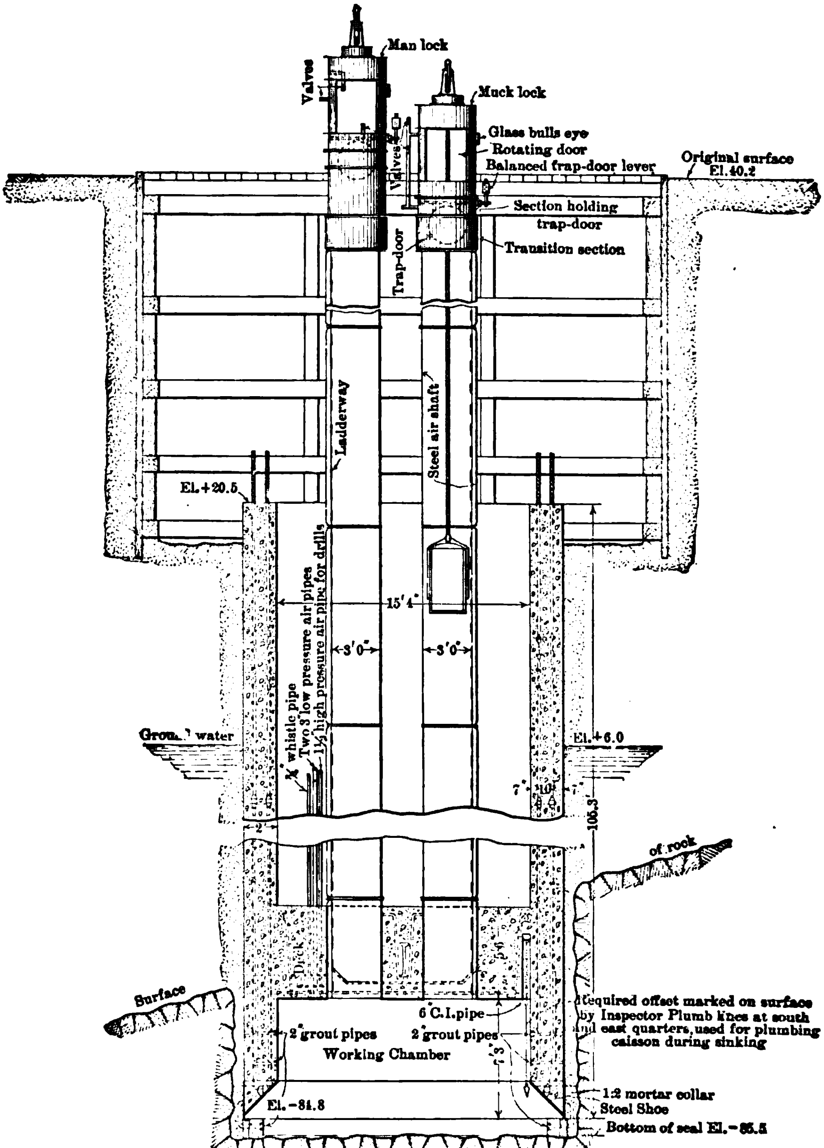
PLATE 228.—Contract 67. Compressed Air Caissons, Showing Apparatus and Method of Sealing into Rock. Caisson dropped from position 2 or 3 feet above bench to final position.

best practice of caisson sinking. The caisson was started at the top of a steel shoe bolted up at the bottom of the valve chamber excavation 23 feet from the surface. The shoe is 2 feet 3 inches high and built up of two $\frac{5}{8}$-inch plates, the inner plate being at an angle of 45 degrees with the horizontal, and the two plates coming together at the bottom to form a cutting edge 3 inches high. The shoe was tied in the concrete above by flat straps. The caisson was built to a height of 105 feet with the aid of a 3-ton derrick having an 85-foot boom, the same steel forms being used as described.

Concreting Caisson of Shaft 20. Concrete was mixed in one-cubic-yard Ransome mixer, fed from bins below the surface in the valve chamber. The mixture was 1 part cement to $1\frac{1}{2}$ of sand and 3 of gravel, and was placed between the forms by 1-yard bottom-dumping Stuebner buckets operated by a derrick. A steel plate covering with a square opening was bolted on the top of the inside forms for a working platform, the opening being covered with planks during concreting. Concreting was done at an average rate of 20 buckets per hour. The placing of reinforcing rods was done by hand and by the aid of a derrick. Of the 54 eight-hour shifts working on the building of the 105-foot caissons, 9 shifts were used in concreting, 12 in moving of forms, 5 in deck reinforcing and concreting, and 28 in placing reinforcing rods. The rods were bent to the required curve around a 10-foot bull-wheel, by a lever pivoted at center of the wheel and rotated by the men.

Compressed-air Plant for Caisson at Shaft 20. To furnish compressed air, a temporary compressor was used; later one of the compressors of the permanent shaft-sinking and tunneling plant. The temporary compressor was a single-cylinder, 12-inch stroke, $18\frac{1}{4}$-inch diameter, connected to 150-K.W., 240-volt, D.C. motor. The main compressor was a compound Ingersoll-Rand compressor with intercooler between the $18\frac{1}{4}$- and the $11\frac{1}{4}$-inch cylinders, with a 16-inch stroke and direct-connected to a 164-H.P., 6600-volt, A.C. motor, and was used to furnish both the low air for the caisson and the high pressure for the Jap drills. The compressors pumped into air receivers piped to the gauge-tender's shanty and thence by two lines into the working chamber, these lines having valves and gauges operated by a tender who maintained the desired pressure for the working chamber. The high-air line for the drills led directly to the working chamber.

Locks for Caisson. The electric lights were carried down the man-lock. The bucket in the muck-lock held 10 cubic feet of



SECTION A-A

PLATE 229.—Contract 67. Concrete Caisson for Shaft 20, Showing Method of Sealing into Rock.

FORCE

The average shift in caisson consisted of 1 foreman and 6 sand hogs, with a lock tender working 8 hours.

The average force on top for the entire 3 shifts of each day consisted of 1 day and 1 night superintendent, 3 foremen, 20 laborers, 16 pipemen and mechanics, 3 electricians, 5 carpenters, 3 compressor engineers, 6 hoist runners, 6 signalmen, 3 blacksmiths and 3 helpers, 3 timekeepers, and 5 teams.

EXCAVATION PROGRESS

Lbs. per Sq. in. Air Pressure.	Shifts.		Material.	Cu. Yds. per Hour
	Number.	Hours Worked		
0 to 22	18	8	Fine sand	3.6
22 to 30	5	6	Fine sand and boulders	3.6
30 to 35	12	4	Gravel	2.1
30 to 35	91	4	Hard rock	0.27
35 to 40	28	3	" "	0.27

Total rock excavated = 119 cu.yds.

About 7 feet of drill hole and 1.8 pounds of 40% forcite dynamite being used per cubic yard of rock excavated. Two to four Jap drills used.

PROGRESS SEALING TO ROCK

Method shown on Acc. Pl. 228.

Started Dec. 20 at 4 A.M. Finished grouting Dec. 22 at 9.30 A.M.

Setting forms 5 three-hour shifts.

Placing mortar 6.3 cu.yds. in 5 hours.

Removing forms 4 hours.

Grouting 10½ hours.

Forms were removed 11 hours after placing mortar and 412 bags of neat cement grout placed.

Air removed Dec. 23 at 10 A.M.

Total leakage about ½ gallon per hour.

PROGRESS TABLE

Open cut excavated in 17 eight-hour shifts between Sept. 5 and Sept. 23, 1911.

Caisson deck, reinforcing and concreting built in 54 eight-hour shifts between Sept. 27 and Nov. 12, 1911.

Caisson sunk from ground-water level and sealed to rock under compressed air between Nov. 16 and Dec. 22, 1911. The surface of rock, reached at 5 P.M. on Nov. 26, is at El. −71 under east side of cutting edge. Other rock surface elevators are: S, −76.0; W, −76.7; NW, −79.9; N, −76.0.

Caisson Reinforcement

Total metal placed = 183,663 lbs.

Hoop Rods

Inner ring diam. = 16′ 2″. Outer ring diam. = 18′ 6″.

Lap = 38 Diameters

2′–54′	above	toe of shoe	9″	c.	1″	sq. tw. rds.
54′–64′	"	"	12″	"	1¼″	"
64′–81′	"	"	9″	"	1¼″	"
81′–87′	"	"	12″	"	1¼″	"
87′–104′	"	"	12″	"	1″	"

Vertical Rods

54 inner and 54 outer rods. Rods are connected by sleeve nuts except at the joint between 1″ and 1¼″ rods, which is made by lapping 3.2 feet.

1′–87′	above	toe of shoe	1¼″	sq. tw. rods.
87′–97′	"	"	1¼″	"
94′–108′	"	"	1″	"

Material Encountered

Surface to El. −28 is fine sand.

El. −28 to El. −52 is fine sand with some clay.

El. −52 to El. −56 is sand and boulders.

El. −52 to El. is sand and boulders.

El. −56 to El. 66 is fine sand with 5% to 10% clay.

El. −66 to rock is gravel and boulder.

The rock is hard Fordham gneiss with well-defined layers with strike N.E., dipping about 45° down to N.W.

earth and was operated by a 10-H.P. General Electric hoist at 220 volts. The Mattsen locks used are shown on Plates 229 and 230, the bucket being supported by the cable which runs over the sheave-wheel supported by a gooseneck through a 10-inch tapered hole into the lock. The bottom door allows the bucket to descend; the side door allows tipping of bucket for dumping. The man-lock, in addition to an outside valve for decompressing air, was fitted inside with valves for letting air in or out of lock, to be operated by the men themselves. The valve in the man-lock for letting air in was 1 inch in size, and for letting air out was 1 inch reduced to $\frac{3}{8}$ inch. The outside valve on the man-lock was of the 2-inch size.

Sinking Caisson. In sinking in earth a gang of from four to six shovelers was used, who filled the single bucket operating in the shaft. Excavation was kept level, the shoe being usually buried 3 feet in the sand. Enough air pressure was used to keep the material dry. The caisson was kept plumb by watching plumb-bobs suspended from the deck of working chamber. At 17 pounds pressure, 138 cubic feet of free air per minute was used; when rock was reached, the working pressure in the chamber being maintained at about 34 pounds, 874 cubic feet of free air per minute compressed to 108 pounds was used. The leakage increased considerably when rock excavating started, as it was necessary then to expose the cutting edge. This was prevented in a large measure by banking the slope of the shoe with clay, loose or in bags, or clay mixed with straw. This caisson was found to be heavy, the friction amounting to about 630 pounds to the square foot, so that it was necessary to support the caisson either on knobs of rock or on the perimeter on timbers. While supported on three $12'' \times 12''$ timbers and when cutting edge was 4 feet from the rock, everything being ready for the final seal, three posts were crushed in and the caisson dropped 3 feet, making it necessary to excavate that much more rock for the seal. While excavating in rock, 960 cubic feet of free air per minute, compressed to 120 pounds, was used. Four Jap drills were operated, making holes 3 to 4 feet deep, after which they were shot with light charges of 40 per cent dynamite. During sinking in rock, one or two men were constantly "mudding up" between rock and the cutting edge.

The "Bends." A good deal of trouble was experienced in getting the men to come out slowly enough to avoid the "bends." As the caisson locks were of small capacity, extra precautions were taken to insure tightness of doors, and particularly of the stuffing-

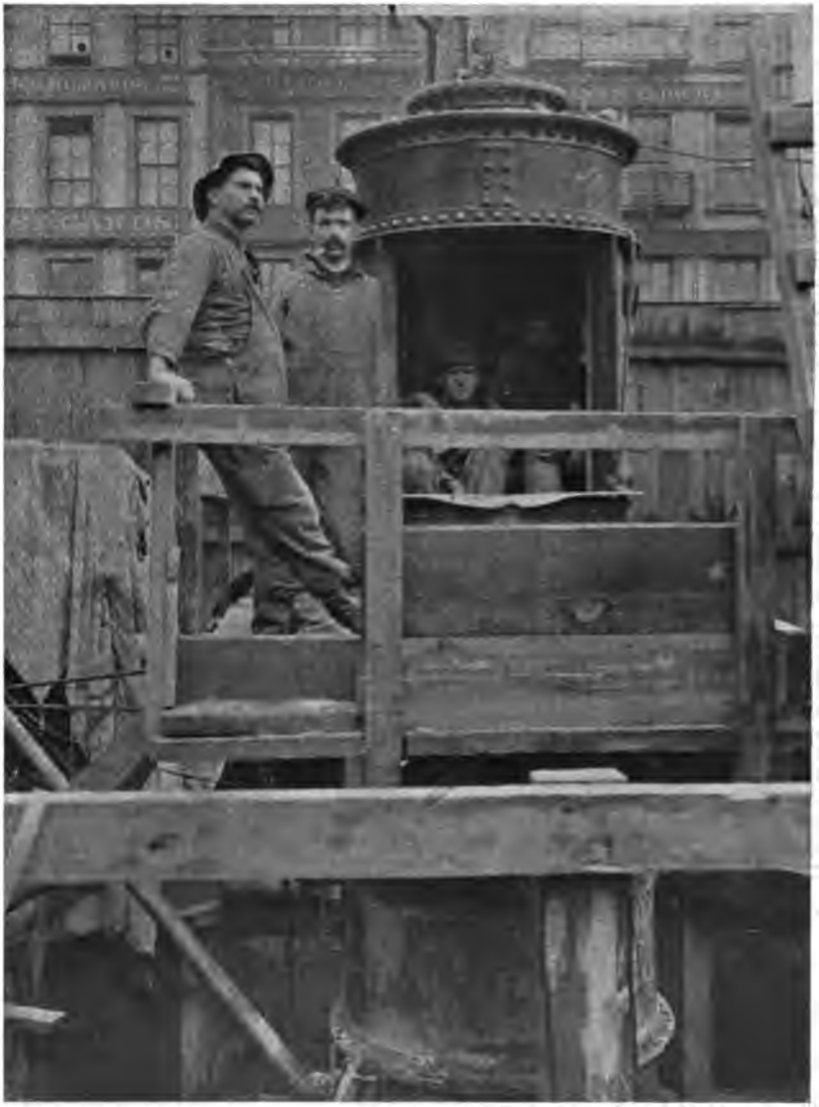


PLATE 230.—Contract 67. Shaft 19. Mattsen Air Lock in Position Over Shaft Leading to Working Chamber of Concrete Caisson. Lock is closed by a revolving door fitting opening and a trap door at bottom.

box through which the hoisting rope operates and from which air leaked out rather rapidly. There were several light cases of the bends, and one fatal case, the hospital lock at the shaft being used to relieve these cases, a physician being in constant attendance. Experience gained at this shaft convinced the contractors that it was desirable to raise the men out instead of allowing them to climb out, as is the usual practice. The ladders in the shafts are vertical, riveted to the sides, and hard to climb.

Sealing Caisson. The method of making the seal is as before described and shown on Plate 228, a 2-foot collar being built. Before the last drop caisson was supported on eight 12″×12″ posts, these being knocked out by sledges and the air pressure lowered. The caisson then descended easily, sealing itself off. After the grout placed back of the caisson was allowed to set for about twenty-four hours, air was drawn off slowly, resulting leakage from rock seal being only one-half gallon per hour. Although the external ground-water pressure on the caisson is at a maximum of about 90 feet, it was found after excavating the interior of the caisson that the 2-foot concrete walls were very tight, only a few square feet of damp area appearing.

Sinking of Caisson at Shaft 23. The sinking of the caisson at Shaft 23 offered the greatest difficulty. After the valve chamber had been excavated to a depth of 30 feet, a steel shoe was set up and the caisson concreted between a steel Blaw and a Logan form, as previously described. The caisson was then sunk to ground-water level (−6 feet) alternately concreting and sinking, after which it was built up to full height, 123 feet from cutting edge, projecting 76 feet above ground. This was accomplished with difficulty, even with a derrick with an 85 foot-boom set up on a platform. The caisson, which had an outside diameter of 24 feet and was three feet thick, then weighed about 2300 tons, including 2.2 per cent of steel reinforcement, and was equipped with a reinforced concrete deck 6.5 feet thick, allowing 7 feet head room above the cutting edge. Two 3-foot lengths of steel shafting were concreted in the deck and carried up in 15-foot lengths to above the top of the caisson. Each shafting was topped with a Mattsen lock in which was operated a bucket by means of small electric hoist and cable. Both locks were equipped to carry men and muck and contained an equipment of valves and gauges by which the men could let themselves in and out at any desired speed. This double equipment was found to work very well, and great

PLATE 231.—Contract 66. Shaft 23. Concrete Caisson which was Sunk to 100 Feet below Ground-water under Maximum Air Pressure of 45 Pounds. Length of Caisson 123 Feet. Sunk to ground-water level and built to maximum height before putting on air pressure.

speed was made, both hoists being used for raising men and mucking. In three days the caisson was sunk about 36 feet, the coarse sand excavated being dumped inside to give weight. Friction was such that the added weight was given by pumping water into the caisson, saturating the 90 feet of sand inside.

Collapse of Steel Shafting. At this point the excavation was stopped, so that the locks could be raised to allow a pig-iron deck to be placed by extending the shafting. This had been done with one lock, and the other lock was just in place, the shafting being under normal pressure, obtained by closing a door in the working chamber placed at the bottom of the shaft for this purpose, when the pressure of the wet sand, not being compensated by the 17 pounds of internal pressure, collapsed one shaft (which was soon followed by the collapse of the other) and the working chamber and both shafts were filled with sand and water to ground-water level. Very fortunately no men were inside the chamber, although frequently air locks are raised while men are at work.

The sand was excavated and the wrecked shafting removed. The various lengths had collapsed in interesting ways, some being completely flattened, others falling in two directions, forming a Maltese cross in section. An attempt to get down in the open to the concrete deck failed, the water boiling up from below through the wrecked shafting. A heavy temporary timber deck was then constructed above ground-water level and a single line of shafting with an air lock built into it. Air pressure was then put on and the material over the concrete deck was rapidly removed. The wrecked shafting in the deck was cut out with an oxy-acetylene blowpipe, new shafting was substituted and concreted in, and an extra foot of concrete was placed on the old deck. To prevent the repetition of the accident described, the two steel shafts were enclosed in a rectangular block of concrete to a height of about 60 feet above the deck, and thus relieved of the pressure of wet sand. The air locks were placed high enough to enable a heavy pig-iron platform to be placed. Sinking was then resumed as before, and proceeded rapidly until rock was reached at elevation −95 in 6 days. Friction on the side of the caisson for some reason proved to be much greater than elsewhere, necessitating the placing of 2300 tons of pig iron and wet sand. This may be attributed to the great depth of coarse sand penetrated. Strangely enough when the rock was reached the friction rapidly fell off, and great quantities of pig iron were removed.

PLATE 232.—Contract 67. Shaft 23. Steel Shafting, Collapsed by External Pressure of Wet Sand while Sinking Caisson.

Frictional Resistance of Caisson at Shaft 23. The friction on outside of caisson at Shaft 23, as determined at various depths of penetration, was as follows:

45 feet	1411 lbs. per square foot
65 feet	1450 "
86 feet	1202 "
116 feet	872 "

Although there was a considerable depth of fine sand over the rock, the theoretical water column pressures had to be carried.

Rock Excavation under 45 Pounds Air Pressure. The rock excavation was made with the aid of Jap drills, a pressure of about 115 pounds being carried at the compressor, giving a net working pressure of about 70 pounds. Two compressors were used, a low-pressure Ingersoll-Rand and high-pressure two-stage compressor, a part of the permanent equipment. It took both compressors working at full capacity to furnish sufficient air. The low-pressure compressor could compress 900 feet of free air to 45 pounds, the high-pressure compressor 1300 feet of free air to 110 pounds. The excavation of the rock was made under 45-pound pressure, the men working two hours per day in one-hour shifts, with five hours off between shifts. To keep the work going continuously, 12 sets of men (usually 7) were employed at the rates previously given. The men suffered little from the "bends" and appeared to realize the dangers, taking from 20 to 30 minutes to come out of the locks. It is believed that the relief from the usual long climb up vertical ladders obtained by hoisting the men out was of material assistance. Although the men worked with a will, it took 351 hours to excavate 161 yards of rock, from which the high cost of this work can be appreciated. Just before making the seal, a bearing of one of the compressors burned out under the continuous twenty-four hour grind. The other compressor not furnishing sufficient air, the men were taken out. The pressure dropped to about 40 pounds, and the working chamber was filled with about 2 feet of sand. The compressor was soon repaired and the work resumed.

Sealing Caisson into Rock (Shaft 23). The final seal was made by dropping the caisson onto the usual concrete bench and oakum. Pressure was drawn down to 36 pounds in a few minutes, this being equivalent to pounding the caisson with a load of 298 tons. After the space around the caisson at the bottom was grouted, the air was drawn off and the leakage found to be about 7 gallons per minute. This was much larger than the other shafts, but the conditions here were much more severe, the seal being made under a head of over 100 feet of water. It is believed also that the run described brought the sand to the bottom cutting edge before the final drop, so that some of it mixed with the oakum on the bench when the air was drawn down for the last drop. A little of the fine sand was then washed out between the oakum and cutting edge, so that some water was allowed to flow in. The leakage found was not at all serious, and was readily taken care of in the sinking. In this connection, it is believed that a more certain seal can be made by loading the caisson until it is "heavy" before the final drop, thus avoiding the necessity of "pounding down" the caisson by drawing off air within the working chamber. In this way one would be sure that the cutting edge dropped on clean oakum and not on a mixture of sand and oakum. With the caisson heavy, it would be necessary to support it on timber posts which could be shot out with dynamite before the final drop, as was done at Shaft 19.

Shaft 21 in Earth. The excavation of the upper portion of shaft 21 offered a problem peculiar to itself. The contract drawings indicated two methods—one to sink separate caisson or the shaft proper and several smaller ones for the foundation of the drainage chamber and the building to be constructed over the shaft. The caisson for the shaft proper would have had to be very large and of irregular shape. An alternate method suggested by a note in the drawings was to enclose the area of the shaft and valve chambers by rectangular caissons. As this plan was preferred by the contractor, permission to follow it was given.

Construction of Wall Caissons at Shaft 21. Four rectangular caissons about 37 feet high and from 38 feet to 43 feet were constructed of wood in the manner usual for foundation caissons. The cutting edge was formed from 6″×12″ yellow pine strips, and the working chamber was sheeted horizontally with 4-inch planks and vertically with 2-inch planking carried up to the top of the caissons. The 6-foot chamber was roofed with 3-inch planks and braced about every 5 feet by 6″×12″ frames about 12 feet high. The portion above the chamber was tied together at about 5-foot intervals with bolts carried through pipes in the interior, placed so as to act as spreaders and which after concreting allowed the removal of the bolts at each end of the caisson above the working chamber. The space above the deck was filled with 1:2:4 concrete to form a foundation for the building. Above this temporary 1:5:10 concrete was placed to act as a dam to keep

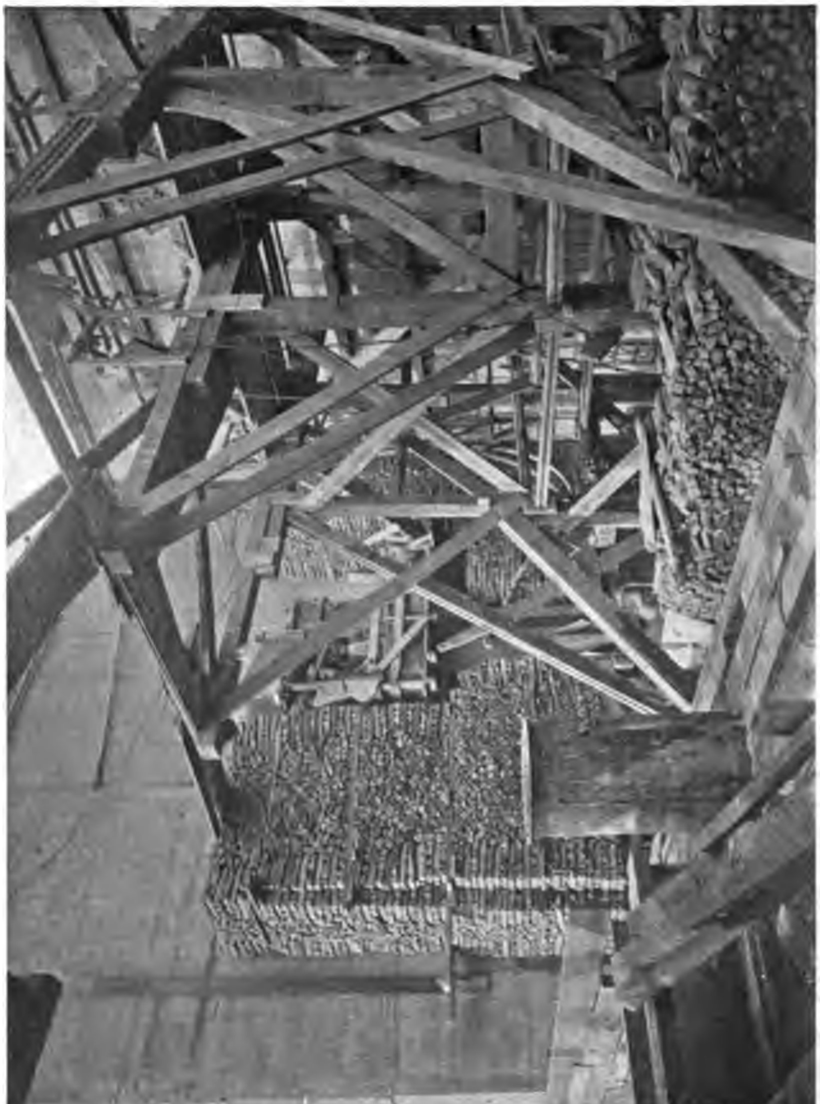


Plate 233.—Contract 67. Shaft 21. Sinking of Wall Caissons for Enclosing Area above Shaft. Showing pig iron piled on top of caisson to overcome friction against gravel.

ground and tide-water out of the enclosure. At each end of the caisson a recess was formed, called a "half-moon," being the term originally used when semicircular keys were formed between adjoining caissons to form a water-tight excavation, to permit the interior cellar area below high buildings and between rock and ground water to be utilized. In this case the "half-moon" was trapezoidal in shape, $3' \times 2' \times 3'$ deep. The working chamber was reached through a 3-foot steel shaft and Mattsen lock. A temporary plant was installed, consisting of a boiler, steam-operated Ingersoll-Rand compressor and a stiff-legged derrick mounted on a platform. The wooden caissons were built on the deck and swung into place previously to concreting by the derrick.

Sinking of Wall Caisson at Shaft 21. The caissons were sunk one at a time, the material excavated from each being a mixture of sand, gravel, clay and boulders. The working chamber was divided by interior cross-braces into seven pockets, three on either side of the bucket compartment. One man was generally worked in each pocket, the material being cast from pocket to pocket toward the bucket. Many of the boulders were of large size and had to be blasted into smaller pieces for handling.

The caissons were invariably sunk in "jumps" of from 12 to 24 inches each by lowering the air pressure. They buckled readily during the sinking under the excessive weight of pig-iron when the cutting edge was jammed on the boulders, the working chamber buckling inward and its longitudinal distortion necessitating additional interior braces, so that the difficulties of sinking were increased.

Sealing of Wall Caissons to Rock. During sinking it was necessary to "mud" or paint with grout the wooden joints and cracks of working chamber to prevent the air from escaping and flowing freely through the loose ground around the caisson. When the rock was reached and the sheeting carried, board by board, down from the cutting edge to the surface of rock in deep pockets the air loss increased rapidly, it then being difficult and almost impossible to get enough pressure to dry out the low pockets in the rock, as the ground would not hold the increased pressure. A feature of the wooden caissons was their lack of rigidity against stresses, especially in the working chamber, and they therefore buckled and conformed to stresses without rupturing. The east caisson was the last of the four caissons to be sunk, and profiting by the experience gained, several improved methods of working were carried out here:

(1) The wooden joints in the interior of the working chamber were caulked with oakum by the sand-hogs, as it was found that the wooden joints dried out and shrank and oakum placed prior to sinking could be pulled out in dry lumps.

(2) Very little pig-iron was loaded on, and only as needed, to avoid making the caisson heavy and jamming the cutting edge down on the boulders.

(3) Packing the surface with excavated material and keeping the pressure within the caisson low, to prevent blowholes in the adjacent ground.

Air Used in Sinking Caissons. A steam-driven compressor, which compressed $6\frac{2}{3}$ cubic feet of free air for each revolution, to a pressure from 3 to 4 pounds higher than that needed in the working chamber, made from 70 to 90 revolutions per minute. When rock was reached and cleaning of its surface began, the compressor made from 125 to 140 revolutions; when concrete covered the entire bottom up to the cutting edge, it dropped down to 70 to 90, as before.

Support of Building. An adjoining reinforced concrete coal pocket was carried on horizontal I-beams supported by screw-jacks, so that any settlement of the building could be taken up. Below the I-beams the foundation settled about $1\frac{1}{2}$ inches, but the opening between was subsequently caulked, the building suffering no damage.

Excavation of "Half Moons" and Interior. After all four caissons were sunk they were found to be out of plumb about 10 inches and out of level end to end, in one instance, 1 foot. This caused the caissons to be separated at the bottom of the half moons from 3 inches to 16 inches. The half moons were unwatered by Cameron pumps suspended from pipe tripods, and as the water was lowered the interior bracing was removed by hand and sheeting placed between the joints of two caissons. The boards of the working chambers were removed, allowing contact between the concrete in the working chamber and that placed in the half moons, to tie the adjoining caissons together and to form watertight joints. The concrete was placed in the open without the assistance of an air lock. The interior was excavated with a derrick and the bracing placed as the depth increased. The rock on being exposed was found to be irregular, hard and very seamy. Very little water came through the seal placed in the working chamber, but two of the joints at the ends of the working chamber made under compressed air leaked a total of about 100 gallons per minute.

Advantages of Concrete over Wooden Construction for Caissons. The work at this shaft brought out sharply the advantages of the concrete caisson over wooden ones. A properly designed concrete caisson has the following advantages over the wooden construction:

1. It is much stronger and not subject to distortion from boulders.

2. It is tighter, holds air better, and is not subject to the heavy leakage of wooden caissons, whose joints require continual mudding up and which are, nevertheless, opening all the time, due to drying out by the air.

3. It is not subject to fire. Serious accidents have frequently occurred in wooden caissons where large timbers in the working chambers have been consumed like matches by the excess of oxygen in the compressed air.

Excavation of Rock in Shaft 21 and Grouting of Leaks. The rock excavation for the shaft was continued with the permanent Ingersoll-Rand compressors installed. The rock was very hard and seamy, necessitating the use of large tripod piston drills. Upon blasting it was found that the powder worked through the seams, opening up leaks under the north caisson, and allowing the leaks at the corners to be diverted through seams into the shaft, rendering the excavation very difficult. A temporary concrete blanket was placed below the north caisson and the seams through which runs occurred grouted. It was found that the grout worked through the porous ground overlying the rock to the surface. Previously the leaks at the corners were collected in boxes built there and heavily concreted over. Pipes from the corner boxes led the water to a sump above the shaft, whence it was raised to the surface. Although the blanket of concrete was placed against rock bottom and concrete in the caisson, when it was attempted to cut off the leaks by forcing grout into the boxes, water and grout were forced through the rock seams into the shaft. It was then decided to sink the shaft for 25 feet to sound rock, place an outer concrete lining back of wooden forms and grout off the leaks through pipes placed to act as weepers and grout pipes. The shaft was sunk narrow to avoid going under the north caisson. and 5 feet of wooden form and concrete was placed at the bottom. The trimming of the tight rock above was done from the form. This was repeated until the surface of the rock was reached. This was thoroughly cleared off and covered with a blanket of about 3 feet of concrete. The shaft was then grouted at about 100 pounds pressure, and nearly all the leaks stopped. The wooden forms were left in place so that grouting could be done soon after concreting. This method was supposed to yield better results, the wooden forms preventing the grout from breaking away at leaky joints or porous areas, if there were any. The corner leaks were completely stopped.

Progress in Shaft Sinking. The shaft sinking was then resumed and good progress made—about 24 feet per week, about 17 cubic yards per foot of excavation—with the handicap of an irregular shaft and 30 gallons of water. The concreting and grouting of the top changed the very unfavorable condition for sinking to favorable, thus amply repaying the contractor for the work done. It illustrates anew the great advantage of placing a concrete lining in shafts troubled by bad rock and water.

Lining Shaft 21. After sinking to a depth of about 100 feet with the derrick, the outer lining of the shaft was placed, and the shaft in earth built between inner and outer forms to serve as a foundation for the steel head-frame. The shaft in earth corresponded to what would have been built and sunk with a concrete caisson by the original contract plan, but this was now easily accomplished in the open.

Riser Pipe. The 4-foot riser pipe at this shaft is to be over 700 feet long, leading directly from the tunnel to the shaft cap in the valve chamber. The contract drawings show that the pipe was to be lowered and grouted into place in a hole formed in the outer lining. The pipe was to be bolted up with an inside flange and afterwards lined in place with a $4\frac{3}{4}$-inch mortar lining, which together with the grout outside would permanently protect the metal. The contractor was given permission to use the following method:

1. To build the pipe in 10-foot lengths with outside instead of inside flanges.

2. To concrete the pipe in with the outer lining, which is to be placed in stretches of about 100 feet while sinking shaft. Lead gaskets are used between the pipe lengths. Slip joints with sleeves to be slipped over gaps between the pipes are used at the bottom of each stretch of concrete and caulked by pouring lead between the sleeve and pipe. In this way, the placing of the riser pipe was much facilitated.

Plant at Shaft 19 for Sinking. The excavation of shaft in rock was first started at Shaft 19, where the compressed air work was of shortest duration. The temporary plant used for the caisson sinking was removed, with the exception of the steam derrick engines for a time used in sinking. A 75-foot $15\frac{1}{2}$-ton steel head frame was furnished and erected upon the concrete caisson by the Lackawanna Bridge Company. (See Plates 225 and 226.) It was estimated that the steel head frame, deducting salvage, will cost about the same as timber frames and will be much more rigid and serviceable. Time was also saved in erection, as it arrived on the ground ready to bolt up. The steel frames at all six shafts are of the same design, with the heights varied by adding to or taking off bottom members. The head frame is equipped with two permament 5.0 diameter sheave wheels of cast-iron rims and steel spokes. For safety in operation the outside of the head frame is bordered in to the level of the dumping platform, at which level two enclosed balanced doors are installed. Instead of the ordinary bull chain or outrigger for dumping the shaft-sinking buckets, a pivoted timber chute was installed. To dump muck the top doors are opened, the bucket raised to the top of the frame, the muck chute lowered to nearly horizontal position and the bucket dumped without leaving the center of the shaft. The workmen below are absolutely protected, as the bucket cannot be dumped without closing the top doors. With this device, such accidents as have occurred from stones or buckets falling back into the shaft are prevented. In a similar manner the men are protected while concreting by two sliding doors near the top of the caisson, these doors being closed when the concrete flows into the bucket from the chute to the mixer. At Shaft 23 a broken sheave wheel cut the cable, but the bucket was caught by the upper doors, thus avoiding a serious accident to the men working at bottom of shaft.

Electric Hoist. An Exeter Machine Works electric hoist was installed close to the head frame and mounted upon a heavy timber platform about 15 feet above ground. Ordinarily it is considered necessary to mount such a large engine upon heavy concrete foundations, but the hoist was found to work well on the timber foundation. The drum of the engine is 5 feet in diameter and 6 feet 6 inches long. It is operated by a G. E. induction motor. 112 H.P., 440 volts. Hoisting engines operated by alternating-current motors have the disadvantage that it is difficult to hoist at low speeds, particularly with a single sinking bucket. On the Exeter hoist the large band brake instead of being operated by hand levers is tightened by a hand wheel mounted in a column at right hand of the engineman. By setting up the brake with the wheel the hoist can be operated at slow speed with the resistance furnished. This, of course, wastes some power and causes wear on the brake lining, but it adds much to the handiness and smooth running of the hoist. There is also a foot pedal by which the brake can be operated. The engine has also an automatic solenoid brake, which operates when current is shut off. It is equipped with a large dial for indicating the position of the bucket or cage. The revolving hand of the dial operates an overwinding device in a very simple way by throwing a cut-off switch affixed to the dial when the bucket or cage reaches a determined position near the top of the head-frame.

Typical Compressor Plant for Shaft and Tunnels. The permanent power plant installed at the shaft consisted of two Ingersoll-Rand compressors, Type P.E. They are electrically operated by two G. E. motors, 164 H.P. and 215 H.P. at 6600 volts. The smaller compressor is $18\frac{1}{4}'' \times 11\frac{1}{4}$,″ cylinder 16-inch stroke, with a capacity of 900 cubic feet, the larger $21\frac{1}{4}'' \times 12\frac{1}{2}$,″ cylinder 18-inch stroke, having a capacity of 1300 cubic feet. Both are two-stage compressors with "hurricane" valves, and run very smoothly in oil. It was decided to install two compressors instead of one in order to save power, the smaller compressor sufficing for shaft sinking and for the tunnel when little power is needed. The combination is also more reliable, as at least one machine of the two can be counted on to be in operation. In New York City there is a "Peak Load" charge placed upon the maximum demand in kilowatts. This is an annual charge which may be incurred on any day by careless operation of the compressors. A small compressor is less liable to run up such a bill.

Methods of Drilling Holes in Shaft 19. At the outset an equipment of Jap or hammer drills, each operated by one man, was installed as follows: Two 52-pound McKiernan-Terry drills and three 41-pound Sullivan drills, both types requiring hand rotation of the bit; also four Ingersoll-Rand B.C.R. 96-pound Jap drills with self-rotating bit. With these drills excellent progress was made and maintained. Three rounds of holes, the usual cut, side, round and trimming holes, were drilled at night in one shift by five drillers. The cut holes were placed in two roughly parallel rows to secure the advantage of the lay of the rock, which is nearly vertical. Side rounds were nearly parallel to the cut holes and consisted of 12 holes 6½ feet long. Trimming holes were 6½ feet long and 20 to a circle of 17 feet 6 inches diameter. A continuous routine was kept up, drilling in one shift, shooting and mucking cut and side round in another, and shooting trimming holes and final cleaning up in the last shift.

Drill Equipment at Shaft 19. The hammer drills were found to work very well, but the smaller drills gave way to the large rotating Japs, which were capable of drilling holes 7 to 8 feet deep, using 1-inch and 1¼-inch steel, and in the mica schist of this shaft accomplished 50 per cent more than the hourly rate of large piston drills. They have the advantage of handiness and less consumption of power and much lower labor cost. On the other hand they are more delicate than piston drills, frequently breaking, particularly the hammers and steel. The steel sticks more often in the holes, as the Jap drills have no pulling power. The specially hard steel and rose bits are difficult to sharpen.

The experience with Jap drills is summed up in the following matter (to p. 693), contributed by Charles Goodman.

B.C.R. Rotating Jap Drills. The drill is run with compressed air fed into the throttle near the handle. The air passes a butterfly valve, which is merely a flat plate pivoted at its center and flapping to and fro in a vertical groove about ⅜ inch wide. In one position the valve allows air to enter through port holes to the space above the piston cylinder which is forced against the anvil block and exposes some open port holes. The air exhausts through these port holes in the walls of the cylinder which leads to one end of the butterfly valve, where it closes the valve and cuts off the air supply to the cylinder, and partly through similar holes to the top of the anvil block, whence it passes through the center holes of both the anvil block and drill steel, exhausting at the cutting face and thus blowing out the cuttings. The piston rebounds in striking the anvil block, air is again let in by the butterfly valve and the action is repeated.

Directly from the butterfly valve, and without interference from it, air is fed through port holes to the rotation valve. In this way the rotation of the drill steel is independent of the piston action.

The parts most subject to breakage and wear are the anvil blocks, pawls and pawl springs. At Shaft 20 in three weeks ninety-nine pawl teeth were dulled and fifteen anvil blocks were broken by eight machines. The pawl teeth are resharpened and retempered and again used. In this time 648 holes averaging 7½ feet deep were drilled. Thus for each forty-five holes drilled each machine required one new anvil block and seven pawl sharpenings.

Drill Steel. The drill steel used is 1- or 1⅛-inch hexagonal upset to 2⅛-inch for the 2-foot starter and 1⅝-inch for the 8-foot steels. The steels are used in approximately 2-, 4-, 6- and 8-foot lengths and have through the center of each a ¼-inch hole for exhaust air. At the start of the work at Shaft 19 a four-point bit was used, but was abandoned and the six-point bit is now exclusively used because the rock face is cut smoother, allowing easier rotation and less straining of the steel.

A difficulty with all Jap drills is the wear and tear of steel. It is weakened by the hole through its center, and as the man handling the drill may continually change the pointing, so that often the steel bit is at an angle instead of square against the face, torsional strains are induced which snap the steel about 2 inches from the bit, where it is generally weakened by the tempering. The fracture very often presents a plain glassy appearance, due to blows of the adjacent steel before the break is discovered, but the usual steel fracture, however, is occasionally seen.

On August 13, Shaft 20, for drilling 36 down holes (8 to 7 feet deep) twenty-one 2-foot starters; twenty-two 4-foot, fifty 6-foot and fifty-four 8-foot steels were used, a total of 147 steels, which may be considered the usual number for a round. Of these an average of twenty steels will be broken of which three will be the 2- or 4-foot lengths and seventeen the 6- or 8-foot lengths. The actual breakage per day varies from ten to thirty steels and the drill holes lost from broken steel sticking in them will average 30 feet per round.

Tempering Steel. At Shaft 20 each steel is heated to a red heat, sharpened and then allowed to cool slowly for about two hours. It is then reheated and about ¾ inch from the bit end is immersed in water, hardening the point. The steel is then thrown aside and left to cool. Very often the hammer end of the steel is chipped and broken. This end is cut off and tempered in oil or cyanide of potassium solution in a manner similar to that above.

Drilling. Eight machines at Shaft 20 are handled by eight drillers with the occasional assistance of the foreman. A round is drilled in four to five hours; the drills average from 7 to 8 feet per drill hour, including change of bits and all delays. The actual speed while drilling is 15 to 16 feet per hour. As the drills occupy very little space, eight drills can be comfortably used in an 18-foot diameter shaft and still leave room for bucket and steels. An 8-foot depth of holes is considered the economical limit, since the steel binds in the holes and excessive breakage occurs with greater depth. This is in part due to the fact that the steel has no reciprocating motion, but is merely fed forward by the blows from the anvil block.

Whether the hole should be wet or dry seems to be a question. A very dry hole is cleaned rapidly by the exhaust air, whereas a hole slightly damp will mud up, clog the hole, block the exhaust and stop the steel from rotating. When this occurs water is fed very freely and the mud washes out satisfactorily.

When drilling dry holes the entire shaft is clouded with thick dust which is inhaled into the lungs and clogs up the nose. To remedy this the "Automatic Respirator and Smoke Protector" made of rubber, is used with success by the drillers at Shaft 20. These cost about $1 each. A wet sponge is fastened in the nose of the respirator and as the driller inhales, the dust is collected in the sponge. The exhaled air passes out through an opening with a mica clap valve. When six or eight machines are working the sponges get filled with dust in about three hours and are then washed clean and replaced.

Size of Hole. A large size at the bottom of a hole, as is well known, is a considerable advantage, for, when the dynamite charge is heavy near the bottom the pull is better and the rock breaks smaller. In this respect, therefore, the Jap drill is at a disadvantage. A Jap steel hole at 8 feet depth has a diameter of $1\frac{1}{2}$ to $1\frac{5}{8}$ inches, whereas the ordinary $3\frac{1}{4}$ or $3\frac{5}{8}$-inch tripod will bottom an 8-foot hole with from $1\frac{3}{4}$ to $2\frac{1}{2}$-inch diameter, and 1 foot of $1\frac{5}{8}$-inch hole will hold 25 cubic inches of dynamite, whereas 1 foot of 2-inch hole will hold 38 cubic inches of dynamite. In the smaller hole the charge tends to leave guns and to break the muck into larger pieces. This is especially true of the cut which requires a heavy charge to lift it. At Shafts 19 and 20 the guns from Jap drills run from 1 to $1\frac{1}{2}$ feet.

Comparison with the Tripod Drill. All the Jap drills can be taken down in one bucket and immediately put to work. They are readily moved from hole to hole, change steel rapidly and have actually drilled, including all delays, about 64 feet in an eight-hour shift at either of Shafts 19, 20 or 21. At Shaft 14 it took $1\frac{1}{4}$ hours from the time five tripod drills were started down before they commenced work; at Shaft 21 it averages one hour before tripod machines started to work and in addition time is also lost when shifting tripods and hoisting them out of the hole; so that at Shaft 21 only 44 feet is drilled in an eight-hour shift.

The table shows some comparative data.

Shaft No.	Per Cubic Yard Excavated.		
	Drill Hole, Feet.	60 Per Cent Dynamite Pounds.	Electric Power, K.W. Hours for Drilling.
19	6.4	1.8	15
20	6.0	1.9	13
21	5.0	1.8	18
14	6.1	3.0	....

	Type of Drills.	No. of Drills.	Foreman.	Driller.	Helper.	Nipper.	Muckers.	Material.
19	90 lbs. Jap	†7	1	7	0	1	3	Schist
20	90 lbs. Jap	†8	1	8	0	0	0	Gneiss
21	$3\frac{1}{4}$ in. tripod	*9	1	9	9	1	0	Granodiorite
14	$3\frac{5}{8}$ in. tripod	†5	1	5	5	1	0	Schist

* Main part of shaft only, as the auxiliary riser shaft is drilled with Jap drills.
† The excavation diameters of Nos. 19, 20, and 14 are each about 18 feet.

A marked advantage of the Jap drill is that it can be used at the same time with and without delay to the mucking, whereas with tripod drills this could not be done without serious delays. Thus it is possible to drill relief and trim rounds while the previous rounds are being mucked, thus distributing the power required throughout the day and therefore allowing the use of smaller compressor capacity. Each Jap drill uses per minute only one-half the compressed air required for $3\frac{5}{8}$-inch tripod drill.

For tunnel bench in suitable rock the Jap drill would appear to be ideal, as the holes will hold sufficient powder and it practically does not offer any obstructions to the heading work and would eliminate the large percentage of delay usual with bench tripod drills in moving between holes and before they can set up on or start the hole in solid rock.

On the other hand, the tripod drill is less apt to get out of order; its drilling speed while working being very near that of Jap drills, it makes a larger hole. In very hard rock the Jap drill breaks more readily and would prove unsuitable.

However, at Shafts 19 and 20 the drills stood up sufficiently well as to warrant the statement that they were superior in giving safety and economy with as good progress as could have been made with tripod drills handled by an efficient organization. This drill is patented by the Ingersoll-Rand Company.

Progress Made in Sinking Shaft 19. The progress made at Shaft 19 was very constant. Working three shifts, excluding Sundays, between Dec. 11, 1911 and March 20, 1912, 283 feet of shaft were excavated and 259 feet concreted, the speed of concreting being three times that of excavation. The rock in Shaft 19 proved to be uniform medium hard Manhattan schist, with very little water, hardly enough to moisten sides and bottom.

Excavation of Shaft 20 in Rock. Excavation of the rock below the caisson at Shaft 20 started Feb. 15, 1912, seven weeks being consumed in dismantling compressed-air plant, installing head frame and shaft-sinking equipment. The rock below the caisson was carefully drilled and shot as required, so as not to break the seal. Four Ingersoll-Rand Jap drills were operated by the smaller compressor (capacity, 900 cubic feet free air per minute), drilling all the holes for an advance of about 6 feet in one shift. The holes were drilled in three circular rounds with one center or "buster" hole as follows: Eight cut holes, on slope of about 72 degrees to horizontal, to depth of 8 feet, with top of holes on a circle of 4.7 feet radius. Fourteen relief holes with top on circle of 6.7 feet radius to depth of 7.5 feet on slope of 80 degrees to horizontal. Twenty rim holes on circle of 8.1 foot radius to depth of 7.0 feet drilled so as to point slightly outward.

Details of Sinking Shaft 20. The details of the method followed and result achieved are tabulated below from very careful records kept by the engineers of the Board of Water Supply:

Plant at Shaft 22. Sinking in rock below caisson at Shaft 22 began with a plant similar to that at Shaft 19. The area here is much larger and more convenient than at Shaft 19. A set of balanced doors was installed at ground level and were found to be of great assistance in loading and unloading the drills, steel, etc. Above the muck bins sand and stone bins were installed and fed by a Robbins belt conveyor. The bins discharge into a measuring hopper, feeding a one-yard Ransome mixer placed above ground, so as to discharge through a chute directly into concrete buckets in the shaft which are manipulated from two hinged doors, at surface of ground. This plant will be permanent and is placed so as to fill the concrete cars on the cages. Cement will be raised to the level of the mixer by a cement bag elevator.

Progress in Sinking at Shaft 22. An outfit of Jap drills was first used here for sinking. They were found to work well, particularly the large rotary Japs. The rock here is hard granodiorite, an intrusive black granite. This rock is rather too hard

EXCAVATING SHAFT. No. 20

Typical Method

Depth pulled, 5.5 ft. to 6.5 for 3 8-hour shifts.

8 cut holes and 1 buster shot about 7.30 A.M. and then mucked clean.

14 relief holes and guns of cut holes shot about 12.00 M. and then mucked.

20 rim holes and guns of relief shot about 4.30 P.M. and then mucked.

Rock-breakage has many large pieces up to 3-ton chunks on cut shot, and 70 per cent of the mucking is done by hand, the larger pieces being sledged or shot with pop holes. All holes drilled between 10 P.M. and 7 A.M.

Geology.—Well-defined and parallel joints from 1-in. to 3-ft. intervals. Dip 55° to 60° west. Occasional joints are perpendicular and horizontal. Fordham gneiss and Inwood limestone.

Hand or Jap Drills.

Six Ingersoll-Rand hammer drills, weight 96 lbs., B. C. R. 33, machine rotated; average foot drilled per 8 hours per drill 64 ft. The steel bit breaking and getting jammed in hole caused the loss of 35 ft. of hole per round when using 1″ steel, and 25 ft. when using 1¼″ steel.

Cubic Yards. Per Foot.	Pumpage from Bottom. Gallons per Minute.	Average Round.	Number of Drills.	Total Drilling. Per Round.	Drill Hole. Per Cubic Yard.	Forcite Dynamite. Per Cubic Yard. Pounds, 60%.	Mucking.	
							Solid Rock Hoisted per Hour.	1 Cubic Yard Bucket Hoisted per Hour.
8.8	0.0	6.0 ft.	4 to 6	310 ft.	6.0 ft.	1.9	4.0 cu.yd.	9.0

EXCAVATING SHAFT No. 20—*Continued*

Shift.	General.					Expedition.				In Shaft.			Excavation on Top.									Muck Bins		
	Superintendent.	Storekeeper.	Magazine Watchman.	Store Watchman.	Timekeeper.	Foremen.	Riggers.	Carpenters.	Laborers.	Shift Boss.	Muckers.	Drillers.	Foremen.	Comp. Engineer.	Blacksmith.	Blacksmith's Helper.	Electrician.	Topmen.	Signalman.	Hoist Runner.	Pipemen.	Team and Driver.	Laborer.	Grand Total.
12–8	⅔	⅔	⅔	⅔	⅓		1			1	1	6	1	1	1	1	1	1	1	1	2			22
8–4	⅔	⅔	⅔	⅔	1	1	2	4	3	1	9	1		1	1	1	1	2	1	1	2	4	1	39⅔
4–12	⅔	⅔	⅔	⅔	⅓		1		1	1	9	2	1	1	1	1	1	1	1	1	2			27

One Lidgerwood steam hoist, 2 single engines, 8″ bore, 10″ stroke. Cable ¾,″ non-winding, 500′ long. 1 20 H.P. boiler. boiler pressure 100 lbs., head frame 76′ high;. 15½ tons; sheave wheel 5.0′ diameter.

Ingersoll-Rand compound compressor, 18½″ and 11½″ cylinders, 16″ stroke, 900 cu.ft. free air per minute, with direct-connected G.E. synchronous motor, 164 H.P.; 6600 volt, with 6½ K.W.; 125-volt exciter.

High-pressure Air Receiver.—Cap, 235 cu.ft.; 4-in. air line from receiver to manifold with 7½″ connections.

Metered Electric Power Used for Three Shifts = 24 Hours

Kilowatt Hours.				Kilowatts.
Drilling.		Lighting and Blacksmith Forge.	Total for All Purposes.	Maximum Demand.
Per Cubic Yard Excavated.	Used per Day.			
14 *	742	100	842	125

* Includes blowing out smoke. Shaft 19 uses 28 KW. hour per cubic yard.

Note.—Electric hoist at Shaft 19 uses 480 KW. hour in 24 hours.

for hammer drills, so that much steel and parts of drills were broken, but fair progress was made, 2.9 feet per day for a period of seventeen days. Later Ingersoll-Rand F94 piston drills were introduced and used for cut and relief holes, the rotary Jap being used only for the trimming holes. This increased the progress to an average of 4.2 feet per day. Later still, because of trouble with the hammer drills in the hard and somewhat blocky rock

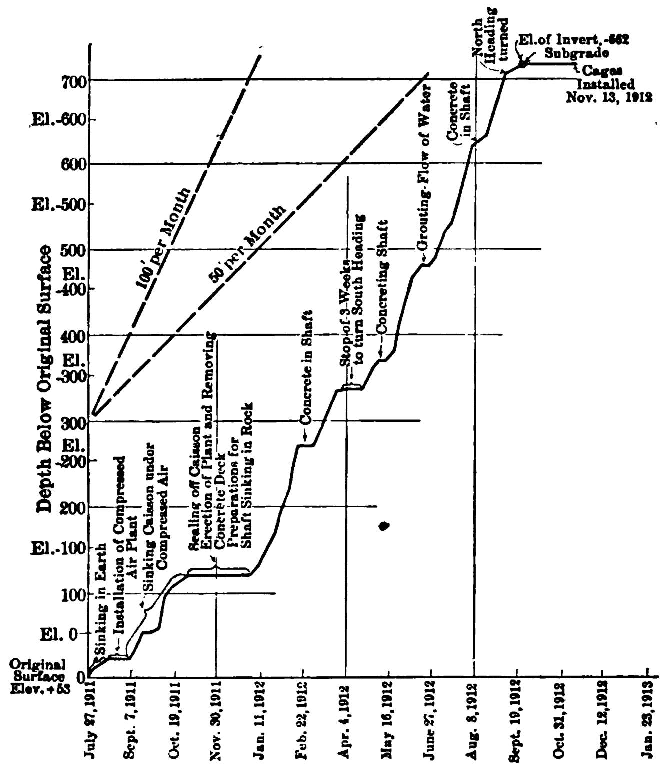


PLATE 234.—Progress Diagram for Sinking of Shaft 22 to Installation of Cages. Includes sinking of compressed air caisson, excavation of upper heading, concreting, etc.

here, the shaft was sunk with the piston drills alone, seven of them being used at a time. Very good progress was made after this, a complete round averaging about 4.63 feet being drilled, shot and excavated nearly every day. Work in the shaft was interrupted only once by water, when about 100 gallons were struck in the drill holes; this was grouted off under high pressure the total delay for the season being about twenty-nine shifts. The fine definite water-bearing cracks in the rock (up to about ¼ inch) were found to be completely filled with cement grout, rendering the shaft at this point nearly dry and amply repaying the time spent in grouting.

Complete Shaft-sinking Data. When the level of the upper level tunnel was reached it was excavated to a length of about 225 feet and shaft sinking resumed after about a month's delay for this reason. While the shaft was being sunk to the lower

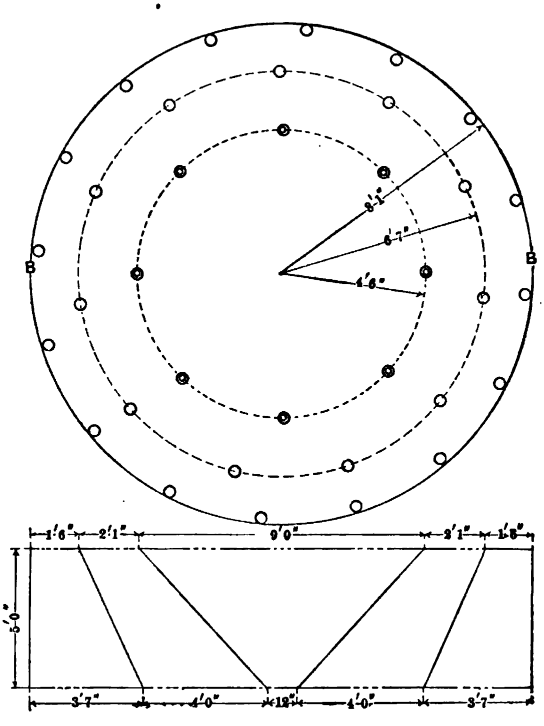


PLATE 235.—Arrangement of Drill Holes as Used for Sinking Shaft 22.

level the magazine chamber in the upper level was being excavated so as to have its use as soon as possible. Very good and consistent progress was made in sinking at Shaft 22, and complete data are for this reason here given. A graphical diagram of the progress at this shaft from the time of starting work is also given, Plate 234, as it shows complete data of shaft sinking, including the installation of plant, sinking of caisson, etc.

EXCAVATION SHAFT No. 22

Elevation, 66.6 to −649.0

Plan of Holes

	No.	Depth	Ft.
Cut	7	7′.6	53.2
Relief	11	6′.3	69.3
Trim	16	6′.1	97.6
Total ft. per round			220.1

Average power used per day:

Lights, Compressor } 1585 K.W. hrs.
Hoist, 229 K.W. hrs.
Maximum demand (average), 175 K.W.

GENERAL DATA

Depth sunk = 582.4. Elev. 66.6–649.0.
Total time elapsed Jan. 4 to Sept. 9, 750 shifts.
Driving south tunnel Mar. 28 to Apr. 26 (inclusive).

Shifts drilling, shooting, mucking	414
" concreting and setting forms	156
" delayed plant trouble	8
" scaling	3
" driving south tunnel	90
" delayed acc't water	29
" no work acc't Sundays and holidays	50
Approx. cu.yds. per ft. of shaft	8.7
Aver. inflow of water, gals. per min.	6
Aver. time drilling complete round	6 hrs. 1 min.
Average time mucking complete round	15 hrs. 35 min.
Average time shooting complete round	2 hrs. 1 min.
Average No. of drills used	7
Depth per hour	5.15
No. complete rounds	129
Average advance per round	4.63

Average time loading and shooting round

Cut, 39 mins.
Relief, 40 mins.
Trim, 42 mins. } 2 hrs. 1 min.

Average 60% dynamite used per round:

Cut, 31 lbs.
Relief, 35 lbs.
Trim, 46 lbs. } 112 lbs.

60% dynamite used per cu.yd.	2.8 lbs.
Exploders used per round	36
Exploders used per cu.yd	1.1
Average No. of buckets of muck raised per day	88.1
—per round	94.3
Average No. of buckets of water raised per day	42
Increase in vol. of muck over rock in place	84%
Drill hole per cubic yard	5.6 ft.

PLANT USED

One Lidgerwood st. hoist, No. 72, cyl. 8½″×10″; 1 30-H.P. Lidgerwood boiler for hoist, used to elev. 276.0; 1 Exeter hoist, 5′ drum; 1 75-H.P. motor for hoist, G.E. 220-volt D. C.; ⅞″ non-winding cable; two 1-yd. buckets; 1 2 yd. bucket; 1 Ingersoll-Rand compressor type P.E. cap. 960 cu.ft. per minute to 100 lbs.; 1 G. E. synchronous motor, 164 H.P., 6600 volts; 1 25-H.P. G. E. 125-volt exciter; air receiver cap. 245 cu.ft.; 6-in. air line.

TYPICAL FORCE ACCOUNT

Shifts.	Superintendents.	Foremen.	Engineer.	Hoist Runner.	Signalmen.	Topmen.	Laborers.	Carpenters.	Pipemen.	Pipemen Helpers.	Drillers.	Drillers' Helper.	Muckers.	Electrician.	Timekeeper.	Storekeeper.	Mag. Watchman.	Nippers.	Dumpmen.	Teamsters.	Animals.
TOP GANG																					
12–8	$\frac{2}{3}$		1	1	2	2								1	1	$\frac{2}{3}$	$\frac{2}{3}$				
8–4	$\frac{2}{3}$		1	1	2	2	2	1						1	1	$\frac{2}{3}$	$\frac{2}{3}$		2	4	8
4–12	$\frac{2}{3}$		1	1	2	2								1	1	$\frac{2}{3}$	$\frac{2}{3}$				
BOTTOM GANG																					
12–8		1							1		7	7						1			
8–4		1							1	1	1		10								
4–12		1							1		1		12								

Sinking Shaft 21. The most difficult shaft sinking on the City Aqueduct was that at Shaft 21, due to the various complications there met. The shaft, being a combination drainage and riser shaft, is very complicated, and of irregular shape, consisting of a large circle with a smaller one close by to accommodate the riser. The larger shaft was sunk in advance with using 6 to 11 Ingersoll, and McKiernan-Terry 3⅝-inch piston drills, the small riser shaft alongside was drilled with B.C.R. rotary Japs, and shot into the adjoining larger shaft. Usually about 4½ feet of shaft were sunk per day which, considering the large section, 17.9 yards, and the hard grano-diorite rock here encountered, was very creditable.

Concreting and Setting Riser Pipe. When the shaft had sunk about 100 feet below the concrete lining or when it was advisable to concrete to cut off water, a platform was set near the bottom, and pouring started, concreting in the steel 4 feet 9½-inch riser pipe which was bolted together in 10-foot lengths with outside flanges and lead gaskets. When a closure was made with the pipe above, the 4¾-inch inside lining of the pipe was placed with the aid of 4-foot diameter wooden forms.

Concrete Plant at Shaft 21. A very convenient plant was erected alongside of shaft, consisting of a 1-yard Ransome mixer, fed from overhead bins which were filled by an inclined belt and bucket conveyor. Trucks hauled the sand and gravel and dumped into below-ground hoppers, which fed the conveyor. Cement was conveyed to the level of mixer platform by bag elevator. The mixer discharged directed into the concrete buckets set upon the doors at ground level. With this plant 160 batches of concrete could be placed in eight hours. This plant when equipped with perhaps an auxiliary conveyor for sand and with large storage bins will serve very well as the plant for lining the tunnel. It usually mixed about 100 yards per 8-hour day.

Grouting Off Water at Shaft 21. The rock at Shaft 21 was notable for numerous joints and seams which frequently carried salt water under pressure. Usually heavy water-bearing seams were encountered about 80 feet apart, necessitating grouting and placing of concrete lining.

The holes tapping water-bearing seams, when yielding up to 20 gallons per minute, were stopped with pipes and valves and grouted with neat cement under about 300 pounds pressure. Usually while the grout was setting a stretch of lining would be placed, so that the delays due to grouting were not large. When down about 500 feet below the East River, the largest water-bearing seams were encountered, but these were successfully grouted off. Up to this point the water in shaft was handled by bailing, but later a pump chamber was excavated inside of the shaft and a triplex motor-driven Gould pump of about 150 gallons capacity, installed. To the roof in this chamber a small horizontal Cameron pump on the bottom discharged. It is believed that the concrete lining of this shaft together with the grouting of water-bearing seams as encountered greatly facilitated the sinking and much expedited the progress. Had this shaft been timbered and sunk without grouting, the amount of water to be handled would have been very large (several hundred gallons) and the difficulties experienced enormous, perhaps comparable to those met at Shaft 4, Rondout siphon.

Sinking Shaft 24. The drilling at this shaft was first done with Jap drills, but it was soon demonstrated that better progress could be made with piston drills (Ingersoll-Rand F94) as the beds were hard and seamy causing a good deal of sticking of the steel of the hammer drills.

Grouting Water-bearing Rock. At an elevation of −230 feet a water-bearing area of rock was tapped, as much as 240 gallons per minute coming through a drill hole, causing the flooding of the shaft. As the compressor plant here was small (900 feet per minute) a temporary steam plant and compressor, such as used for caisson sinking, was erected and the shaft recovered. The holes were finally grouted off, although some of the holes had to be connected to several times, as apparently a slight circulation of water in the seams carried the grout away from the pipes. It is a common occurrence when grouting rock with neat cement to find a pipe which was apparently tightly plugged with cement flowing water when the valves are opened several hours later.

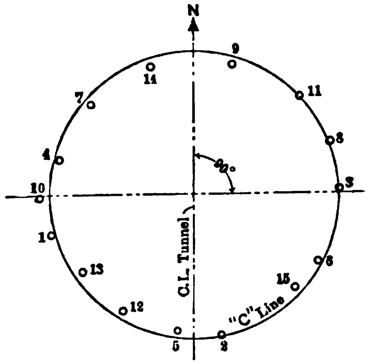


PLATE 236.—Drill Holes Grouted at Shaft 24. Elevation —230.

A belt of about 75 feet of seamy, water-bearing rock had to be passed before dry rock was reached at the bottom. The wet rock was a hard grano-diorite intersected by distinct seams or cracks about $\frac{1}{8}$ inch thick, from which the water issued and which were successfully filled with grout. The concrete lining in this stretch was placed in short stretches and water-bearing pipes grouted off. To give a clear idea as to the method and results obtained by grouting, the following table is appended. It shows clearly how repeated grouting of the same hole was necessary;

GROUTING DATA FOR SEAM AT EL. − 230; SHAFT 24, CITY TUNNEL

Hole No.	Date Dirlled.	Elev. of Bottom.	Depth of Hole.	No. Connections.	Dates Grouted.	Cubic Feet of Grout Taken.	Pressure Used in Pounds.	Length of Pipe.	Remarks.
1	3-25-12	−228.5	7.5′	7	4- 5-12 4- 7-12 4- 9-12 4- 9-12 4-10-12 4-10-12 4-11-12	456.00 85.50 42.75 42.75 19.95 2.85 9.97	135–300 225–300 265–345 300 300 300 300–375	4.0′	Water pressure, shown by gauge, as follows: 4-6-12 = 75 lbs. 4-7-12 = 85 lbs. Max. flow: 240 G. P. M.
2	4-8-12	−230.0	9.0′	2	4- 8-12 4-10-12	131.10 11.40	260–300 270	4.0′	Water at El. − 230
3	4- 8-12	−230.0	9.0′	4	4- 8-12 4- 9-12 4-10-12 4-11-12	57.00 14.25 8.55 4.27	275–300 275–300 300 325	4.0′	Water at El. −230
4	4- 8-12	−232.0	11.0′	3	4- 9-12 4-10-12 4-10-12	51.30 5.70 4.27	275–300 275–300 300	4.5′	Passed through grout El. − 232 Water, El. − 232
5	4- 9-12	−231.0	10.0′	3	4- 9-12 4- 9-12 4- 9-12	14.25 199.50 85.50	275–300 275–300 275–300	4.5′	Water, very slight
6	4- 9-12	−234.0	13.0′	4	4- 9-12 4-10-12 4-10-12 4-11-12	8.55 9.97 11.40 7.12	275–300 300 270 300–375	4.5′	Water, very slight
7	4- 9-12	−237.0	16.0′	1	4-11-12	5.70	300–375	4.0′	
8	4-10-12	−235.0	14.0′	3	4-10-12 4-10-12 4-11-12	5.70 76.95 45.60	300 270 300–375	7.0′	Water at El. − 231
9	4-10-12	−235.0	14.0′	3	4-10-12 4-10-12 4-11-12	11.40 8.55 8.55	270 270 300–375	4.5′	Water at El. − 231
10	4-10-12	−238.5	17.5′	1	4-10-12	11.40	270	6.0′	Water at El. − 237 *
11	4-11-12	−233.0	12.0′	1	4-11-12	5.70	325	7.0′	Little water at El. −231

* Flow of 32.0 G. P. M. after shooting cut.
Total yards grout = 54.2.
NOTE.—Holes inclined outwards 3 feet in 12 feet. No water in holes Nos. 12, 13, 14. Little water in No. 15, flow stopped.

Sinking Shaft 23. Shaft 23 was sunk without difficulty, using the same methods employed at Shaft 24, but no wet rock was encountered, and no grouting done except a little below the cutting edge to insure a better seal. The location of this shaft was most fortunate, as a few hundred feet beyond the wettest stretch of rock so far encountered on the City Aqueduct was pierced by the tunnel.

Summation of Shaft-sinking Methods, Contract 67. The shaft-sinking methods on Contract 67 were undoubtedly as advanced of any employed on the Catskill Aqueduct, and sums up the experience of the entire work. In brief as follows: the plant consisted of steel head frames, enclosed and equipped with protecting doors, permanent direct-connected electric hoists operating non-rotating ropes, and large buckets. Where the rock was suitable, hammer or Jap drills were used to great advantage, particularly the I.-R. rotating B.C.R. drills. In hard and seamy rock piston drills were used to good advantage. In all cases electrically driven high-speed compressors were used. All the shafts were circular and concrete lined and grouting was resorted to so as to practically to eliminate pumping while sinking. In all the shafts, except two, the grouting was a very important feature and almost indispensable in two or three. In addition, while sinking, electric, air and discharge pipe lines were concreted in with the lining, thus clearing the shaft of obstructions and much facilitating the work of installation and adding much to the security of operation.

Equipment for Tunneling. Shaft 21 was down March 15, 1913, all the others at that date having tunneling in active progress. The equipment at each shaft is very similar. The steel head frames, muck bins, electric hoists, compressor plants, etc., used during shaft sinking were continued in use and used to operate the cages and drills. The cage guides were securely fastened to a wooden tower-like framework fastened by expansion bolts to the concrete lining. The 4-inch air, 2½-inch electric and 6-inch water pipes concreted in the shaft lining were used for tunnel purposes and except where much water was struck, as at Shaft 23, proved ample for the purpose.

Cages and Shaft Equipment. The cages were of the balanced Eagle platform type. Instead of the cars being dumped automatically on the cages, as on Contract 66, the cars were pulled off the cages and dumped on a tipple which automatically revolved into dumping position, and returned to the horizontal with the empty cars. The cars were built to the contractor's design and consisted of a base to which were bolted pairs of wheels to a 24-inch gauge. Upon this base steel channels furnished a framework for a box of 38 cubic feet capacity, with pivoted front used for the handling of muck. The box can be taken off and a revolving steel U-shaped Koppel top placed to serve for concreting. This effected a considerable economy, as the costliest portion of the muck car could also be used for concreting. The platform cages with tipple were adapted in preference to the self-dumping type, to save in weight and cost, and because the platform cages are roomier and handier for general purposes.

Automatic Tipple vs. Self-dumping Cages. The automatic tipples used in connection with these cages were designed to secure the advantages of the self-dumping cages, as they allowed the use of muck bins close to the head frame, and the immediate return of the muck cars to the cages and tunnel. It takes two men, however, to shove the cars off and on the cages, whereas the operation is entirely automatic with the self-dumping cages. By making the dumping level the main platform for men and materials also, but one more man was necessary, as a "top-man" is necessary in any arrangement. However, it seems to the writer that the self-dumping cages with muck cars such as used on Contract 63 and 66, are somewhat handier and more economical than the tipples and higher bodied cars used on Contract 67.

Method of Excavating Tunnel. The small tunnels of the contract (15 feet diameter as excavated) in Brooklyn were driven mostly as heading with short and shallow benches. The bench, a few feet high and about 10 to 15 feet long, was drilled after the heading holes were put down by turning the drills on the columns. This allowed most of the muck to be shot over the bench, saving wheeling. As the rock is mostly a hard grano-diorite and the drilling of the headings the slow feature, the mucking of these small tunnels (6.5 yards per foot) was not the governing feature as on the other contracts. General Electric storage battery locomotives were used on this contract as on Contract 66, and gave good service at a low operating cost.

In some of the tunnels three shifts of drillers were employed, it usually taking more than a shift to drill and shoot the headings. The grano-diorite proved to be very variable in hardness, often taking as much as twelve hours to drill with $3\frac{5}{8}$-inch Ingersoll-Rand piston drills. This made it difficult to maintain a schedule such as employed on Contract 66.

Tunneling at Shaft 19 by Three-shift Method. The tunneling method followed at Shaft 19 in the early part of 1913 was that known as the three-drilling shift or continuous method. Between the two headings, three drilling and mucking shifts were employed with three small shifts for setting up the drills. The schedule was such that a complete operation of drilling, blasting and mucking was performed in 16 hours, the tunnel advancing about 7.0 feet. The tunnel was excavated in dry Manhattan schist, which yielded, when 1000 feet long, in the North heading about $2\frac{1}{2}$ gallons of water per minute; in the South, only $\frac{1}{2}$ gallon per minute. It is circular and excavated to about 16 feet in diameter. The usual top heading and bench was employed, the tunnel usually being completely excavated to invert grade about 70 feet back of the fence.

To give the method in detail, the following description is given:

Details of Drilling System. The drilling gangs who work from 12 P.M. to 8 A.M., 8 A.M. to 4 P.M., and 4 P.M. to 12 P.M., upon arriving at the heading find that the drills have been set up by the previous setting-up gang and the muck nearly cleared out by the mucking gang. Two 8-foot columns are set up about 3½ feet from side of tunnel and 4 feet back of the face. Three drills are mounted on one column and two on the other, using 2- and 3-foot column arms, the drills being 3¼ E 44 Ingersoll-Rand reciprocating. To drill the bench with vertical holes a tripod piston drill or rotating Jap drill is used.

Air is supplied through a 6-inch pipe carried down the shaft and branching to 4-inch line in each heading, the 4-inch line being laid on floor of tunnel to within 30 or 40 feet of bench, from which point a flexible hose carries the air to the heading manifold supplying the drills.

The drilling gang for heading and bench, consisting of a foreman, 6 drillers and 6 helpers, usually drills the round in about 6 hours, consisting of six cut holes 10 feet deep, eight relief holes 8 feet deep, and ten rim holes 8 feet deep. The cut holes start 6½ to 7 feet apart and "bottom" within a foot. The rim holes start within 4 inches of the C line and point outward from 6 inches to a foot. The relief holes are distributed between the cut and rim holes. The six bottom holes usually point down about 18 inches. Steels drilling 2-, 4-, 6-, 8-, and 10-foot holes are used, and vary from 2¾ inches for the starters to 1¾ inches for the 10-foot steels. The drills are sharpened by a Lake Shore Engine Works drill sharpener, requiring a blacksmith and helper for each shift. The use of the drill sharpener rather than hand sharpening has been found to be economical and expeditious, but some trouble was experienced from breakage of pistons, due to the severe work required of drill sharpeners. Eight- and 10-foot steels, before sharpening, are usually used twice for holes in the Manhattan schist, the others only once. The + bit is used for all steels.

The bench, usually kept about 70 feet back of face, is drilled by a driller and helper operating a piston or Jap drill. The rows are about 3½ to 4 feet apart and contain five holes. Additional holes are often drilled when bottom breaks high, to allow laying of track to invert grade.

Blasting the Heading. As soon as the heading is drilled the columns, electric lights, etc., are carried back and the dynamite and exploders, each in separate covered boxes, are carried forward. The gelatine dynamite is tightly rammed into the holes with wooden sticks and the stick with the electric exploder is placed in the last or next to the last. About one stick, $1\frac{1}{4}''\times 8''=13$ ounces, per foot of hole is used, but these squeeze to about one-half the depth of hole, after which the remainder is filled with sand tamping in paper bags.

The six cut holes are connected in series and fired from the shooting box by throwing in a switch connecting with the lighting circuit. The lead wires to the heading are hung on the side of tunnel opposite to the electric lighting circuit. After about ten minutes the men go back and connect up the relief round if the cut has pulled well. When the cut holes bottomed closely it was found that the full depth is blasted out at the first shot, or at worst the short guns left would be reloaded with the next or relief round. A poorly drilled cut when blasted will often break only 3 to 4 feet of the "collars" or tops of holes, leaving large burnt-out "guns" or "butts" which are difficult to reload. A good cut determines to a large extent whether the relief round will pull well, which in turn governs the depth of pull of the rim round.

A great aid to blasting is the thorough ramming of the dynamite into the holes so as to get the maximum amount at the bottom with good contact to the sides and to each other. To obtain this the paper coverings of the sticks are often slit. To prevent misfires the electric connections must be carefully made and circuits tested by galvanometer or "blasters' friend."

At Shaft 19, by the means outlined above, extraordinarily long advances, 6.5 to 7.5 feet, were regularly made in the Manhattan schist, whereas at other shafts the advances were only about 5.5 to 6 feet.

The first loading of holes took about 45 minutes and the complete loading and firing $1\frac{1}{4}$ to $1\frac{1}{2}$ hours. The bench holes were usually set off with the cut; when more than one round was fired the last row was set off with the cut.

After firing the bench and cut rounds, the pipe-fitters carry a 2-inch air line with 1-inch nipple to within 30 or 40 feet of heading, the end being weighted down by stones, and remains in place blowing air during shooting of relief and rim holes, and continues for two or three hours, blowing the smoke rapidly towards the shaft.

Ventilation of Heading. A large Roots blower at top of shaft also blows air towards the heading, the 10-inch pipe being carried within 200 feet of heading. The blowers rated at 2500 feet per minute can maintain an initial pressure up to $3\frac{1}{2}$ pounds. A 14-inch pipe is carried down the shaft and branches into two 10-inch pipes which are suspended about 5 to 8 feet above the track. The pipes are of the same type used on Contract 66. The blower is kept going 3 to 4 hours after shooting.

Setting Up Drills in Heading. After a lapse of 15 to 30 minutes, the setting-up shift, a scaler and electrician go into the heading and when the lights are hung, one 16 c.p. light every 30 feet, they commence to scale the roof. The setting-up shift, composed of a driller, helper, and one or two muckers, start to throw back about 6 feet of the muck from the face and set up drills in position ready for drillers as before described. There are three setting-up shifts, which follow the drillers. It has been found economical to use separate shifts for setting up rather than relying upon the regular drillers.

Mucking the Tunnel. About one hour after shooting, muckers will be at work, although they are often detained in the opposite heading for an hour or two longer. The hours of the mucking shift, consisting of a foreman and 22 muckers on the day shift, and 17 muckers on each of the night shifts, are 1 A.M. to 9 A.M., 9 A.M. to 4 P.M., and 4 P.M. to 12 P.M.

Four muckers erect the plank runway from heading, which consists of a double 12-foot plank resting on a 3-inch cross pipe telescoping into a 4-inch pipe for adjustment and supported on ladders against the wall. Meanwhile the other muckers clean the tracks and load cars with the scattered muck from the blast. When the track is sufficiently clear the cars are brought to each side of the runway over 24-inch gauge tracks with 30-pound rails, one side for loading and the other for bringing up empties. Three-car trains are hauled by General Electric storage-battery cars at a speed of 400 to 500 feet per minute.

The heading is mucked with 3 pickmen, 4 shovelers, and 4 wheelbarrows, and two $1\frac{1}{2}$ cubic yards ($\frac{3}{4}$ yard solid rock) cars are loaded in 25 minutes. At the same time the bench muck is being loaded into cars by the other muckers. A mucking shift will load about 52 to 60 cars in 8 hours. The end-dumping muck cars are hauled to the cages by the storage battery dinkies and dumped by automatic tipples at the top into bins, from which it is hauled by teams, taking $3\frac{3}{4}$ yards loose in a load, to the foot of Clinton Street.

When the mucking of a round is completed, 4 or 5 muckers lay overlapping ¼-inch plates, 5′×6′, over entire top of bench and on tracks at foot of the bench. The blasted rock falling upon these plates is much more readily handled than otherwise. Four muckers take down the plank runway in from 15 to 30 minutes and load all the material of runway into a car, which is pushed back out of the way.

The total force at Shaft 19 averaged about 179 men when operating on the three-drilling and mucking shift basis.

Water at Shaft 23. Pumping Plant. So far no unusual difficulties have been encountered save at Shaft 23, where a very heavy flow of water was struck in the drill holes, a few hundred feet from the shaft. While pumps were being installed the holes were grouted under 300 pounds pressure, but the next shot exposed seams yielding about 300 gallons of water per minute. The grout did not penetrate far into the broken-up rock, which appeared to be at a contact with the Fordham gneiss. It is very difficult to grout broken-up rock without well-defined seams, and it hardly pays to persist in tunnels where water is readily handled; whereas in shafts it may be imperatively necessary, as a few hundred gallons of water at the bottom of a deep shaft is an almost overwhelming handicap. A pump chamber was excavated in the side of the shaft, and two 300-gallons per minute Triplex Gould piston pumps installed. They were belt-driven from A.C. motors. They proved to be very smooth working, reliable and satisfactory. The tunnel was then driven ahead after four weeks delay, and a belt of broken-up rock penetrated, yielding at the maximum about 550 gallons of water per minute. The value of the pumping item to the contractor was here shown. Although for the usual small quantities encountered the price of 35 cents per million foot-gallons is not profitable to him, for the larger quantity, such as handled at Shaft 23, with electrically driven pumps, a good daily margin was realized above power and attendance charges, which will probably reimburse him for the cost of installation of pumps, delays due to water, etc., exactly as the engineers hoped would be the workings of this provision.

Mucking Machines for Tunnels. The experience on most tunnels is that it is hard to keep the mucking shifts full, and much complaint is made about the increasing wage ($2 for eight hours), demanded by the muckers, who are said to be of an inferior quality. This has furnished the incentive to strive for a mucking machine which would largely reduce the force of muckers necessary. As stated before, although several types have been tried on the Catskill Aqueduct, none has yet been successful.

Myers-Whaley Mucking Machine. The Myers-Whaley mucking or shoveling machine has been for some time used in mines where it is said to be successful. It was tried out at Tallulah Falls, in Georgia, where representatives of the contractors for Contract 67 saw it at work, and were favorably impressed. However, the conditions here were very unfavorable, the main contractors failing before the machine could be fairly tried out.

Mucking Machine at Shaft 23. Soon after Shaft 23 tunnel was under way a new Myers-Whaley mucking machine was secured, and placed in the tunnel. This machine is motor driven, runs on a 42-inch gauge track, and is very compact and low. It weighs about seven tons, and is 25 feet long, and 4 feet 9 inches wide. The power is applied to shafts and chains so as to propel the machine, operate belt conveyors and a powerful shovel. This shovel moves in a path much as a hand shovel, scooping up the muck, throwing it into a bucket which in turn throws the muck into a belt which passes it, another belt feeding the cars (see Plate 237). The whole machine is pivoted on a king pin so that the shovel can be directed at any point on the bottom. One of the principal features of the machine is a cone clutch through which the mechanism of the shovel is controlled and the machine reversed. The, clutch is set to slip at a designated load (about 1500 pounds) for the shovel and to relieve the machine of undue strains and shocks when the operator attempts too much or when a hard boulder of rock is struck. The machine can load cars on either of two tracks.

The Myers-Whaley machine is a thoroughly designed and well constructed piece of machinery, and wonderfully ingenious, and did good work during its two months of service at Shaft 23. The experience there showed that the work of mucking a tunnel is much more severe than handling coal in mines. Tunnel schedules have to be rigid, and delays are expensive. The machine has repeatedly mucked out the tunnel in two to three hours, and has filled 1-yard cars in two to three minutes. It was found at the outset that a good track was necessary, and special track arrangements to get around the machine. To allow the machine to muck well down, sections of track are laid as for a steam shovel, the sections being built of rails riveted to flat bars, without cross ties. The machine proved to be rather light for the work, so that numerous small delays were experienced, due to breakage and

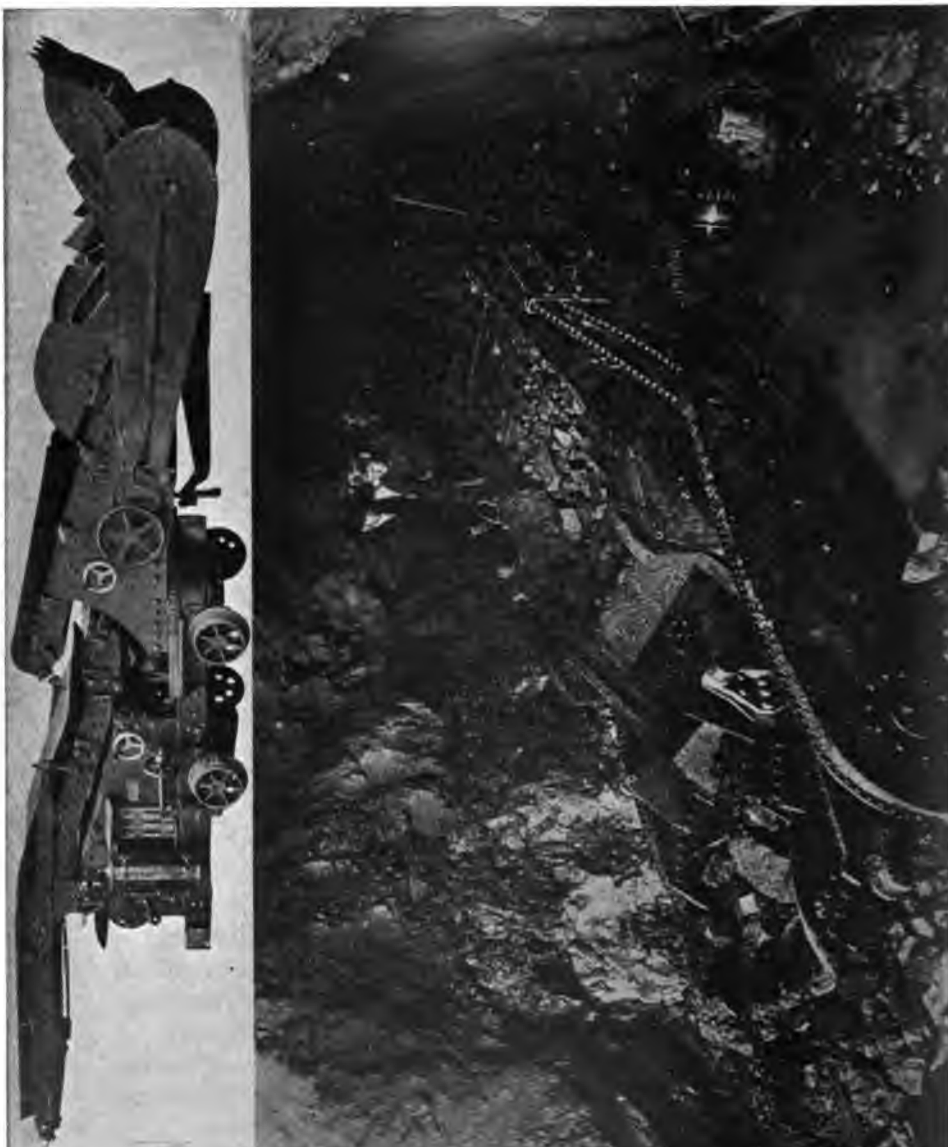


PLATE 237. Contract 67. Myers-Whaley "Mucking" or Shoveling Machine at Work in Tunnel at Shaft 21. Construction of machine shown in upper cut.

derangements of parts. This necessitated a number of men to act as muckers, tracklayers, to clean around machine, to break up rock for the shovel, etc., so that the labor cost of mucking with the machine was little reduced.

The progress made previously to the installation of the machine was not bettered while the machine was in use, but on the average was lower. The most serious delay experienced was when the clutch shaft was broken. The clutch is the critical feature of the machine, for if set too loose it will not do the proper work; if too tight will unduly strain the machine and shaft. No motor troubles were experienced and the machine is readily controlled by the operator by means of lever and hand wheel.

General Observations Concerning Mucking Machine. The contractor reports that the machine can hardly be made to pay on a single small tunnel, as at Shaft 23, but secured a larger and heavier machine for use at Shaft 20, from which two somewhat larger tunnels are being excavated. With a machine of this type—designed to operate in a tunnel too small for steam shovels—it is readily seen that the ordinary system of top heading and bench is not economical, as the cost of the heading muck, which is ordinarily dumped directly into cars, is increased, by the rehandling with the machine. By carrying a short bench and shooting most of the muck over it, the machine can pick up most of the broken rock directly. However, the short bench necessitates drilling the bench with the column drills, and this, where the time of drilling the heading is nearly a full shift, interferes with the schedule. The machine, if capable of mucking out the heading in a few hours, gives a clear passage for the drills, and enables them to be set up sooner, and otherwise helps. A tunnel with a mucking machine must be run on a different basis from that ordinarily pursued and requires a different grade of tunnel superintendent, etc. With two headings in which to work the machine it is more likely to pay for itself by the increased amount of muck handled and in the saving of men and time made.

Mucking Tunnel at Shaft 20. The improved Myers-Whaley mucking machine has now been working for several weeks at Shaft 20 and has given much better satisfaction than the previous one used at Shaft 23. The rock so far handled by the machine at Shaft 20 has been Inwood limestone, which breaks up very fine upon blasting and is dry and rather easily handled. The machine was worked for some time in both headings, but so much time was lost in turning at the shaft that its use was confined to one heading where is has worked to good advantage, using about six muckers to aid the machine, saving about six men per shift. In this heading the best week's progress to date has been 83 feet, but conditions were unusually favorable.

It now seems clear that the success of the machine depends upon its durability, whether it can stand the hard work in the tunnel long enough to pay for the expense of the installation.

Method of Computing Tunnel Excavation and Excess Concrete. Every effort was made to drive all the tunnels closely to the C line and thus save as much excavation, mucking, and disposal charge as possible, the contractors heartily cooperating with the engineers. The tunnels which have thus far been trimmed have come remarkably close to the circular shape, but it is felt that, in the circular tunnel, it is rather difficult to get the bottom close and that a section as used on Contract 90 (Plate 138) would be preferable, and for a given circular waterway and thickness of lining result in about the same actual excavation. To make the method of paying for excavation and excess concrete clear, the following is given: Excavation is always paid to the B line, whether excavated closer or not. Excess concrete is computed for 100-foot stretches by deducting from the actual excavation in any 100-foot stretch the theoretical volume to the B line. The sum of the positive volumes for any tunnel gives the excess concrete, which is paid for at a price fixed in advance by the contract. All the cement is paid for separately, whether or not in excess concrete.

PROGRESS TUNNEL EXCAVATION

FOR WEEK ENDING DECEMBER 18, 1912.

Shaft.	Tunnel Diameter.	Previous Record Week's Work Combined Headings.		For the Week.		To Date.	
		Heading.	Comp. Tunnel.	Heading.	Bench.	Heading.	Bench.
1 N	15 ft.	80	82	40	41	1048	997
1 S	"			31	30	1036	974
2 N	"	83	85	34	32	1375	1310
2 S	"			38	51	897	851
3 N	"	80	83	36	36	1006	897
3 S	"			34	38	1710	1647
4 N	"	87	85	37	46	1146	1086
4 S	"			42	51	1163	1102
5 N	"	98	100	34	36	1284	1257
5 S	"			39	43	1334	1299
Total for Contract No. 63				365	424	11999	11460

PROGRESS TUNNEL EXCAVATION—*Continued*

Shaft.	Tunnel Diameter.	Previous Record Week's Work Combined Headings.		For the Week.		To Date.	
		Heading.	Comp. Tunnel.	Heading.	Bench.	Heading.	Bench.
6 N	15 ft.	86	85	40	42	881	868
6 S	"			43	43	899	885
7 N	"	80	86	39	35	465	429
7 S	"			55	53	654	593
8 N	"	89	83	46	42	541	505
8 S	"			44	38	619	589
9 N	"	65	74	30	37	347	318
9 S	"			35	23	370	336
10 N	"	131	87	56	47	519	412
10 S	14 ft.			56	43	1225	1149
11 N	"	82	78	28	57	491	419
11 S	"			33	42	478	406
12 N	"	91	92	49	14	631	563
12 S	"			63	79	1031	986
Total for Contract No. 65........				617	595	9151	8458
13 N	14 ft.	124	128	61	71	1357	1290
13 S	"			46	38	1523	1468
14 N	"	112	117	61	61	1978	1931
14 S	"			Completed	0	1664	1657
15 N	"	123	125	20	42	1961	1948
15 S	"			50	33	1995	1907
16 N	"	103	107	65	73	1856	1806
16 S	"			Completed	Completed	1189	1173
17 N	"	105	106	Completed	Completed	1098	1114
17 S	13 ft.			Completed	Completed	1649	1593
18 N	"	136*	152†	65	65	2445	2416
18 S	12 ft.			61	63	2402	2377
Total for Contract No. 66.........				429	446	21117	20680
19 N	12 ft.	77	73	45	42	273	255
19 S	"			50	55	259	251
20 N	"	43	37	12	11	94	70
20 S	"			0	7	86	69
22 N	11 ft.	112	112	58	58	361	351
22 S	"			46	46	317	307
23	"	60	63	54	54	898	890
24	"	67	67	56	57	1115	1100
Total for Contract No. 67.........				321	330	3403	3293

* L. Eblir, Supt. † P. Paglioni, Supt.

THIS WEEK:

Record progress: L. Eblir, Supt. No. 18, 126 ft. in two headings.
" " " 127 ft. completed tunnel two hdgs.
" E. Duffy, Supt. No. 16, L. Eblir, Supt. No. 18, } 65 ft. in one heading.
" J. Conners, Supt. No. 12, 71 ft. completed tunnel one hdg.

PROGRESS TUNNEL EXCAVATION

For week ending April 2, 1913.

Shaft.	Tunnel Diameter.	Previous Record Week's Work Combined Headings.		For the Week.		To Date.	
		Heading.	Comp. Tunnel.	Heading.	Bench.	Heading.	Bench.
1 N	15 ft.	80	82	38	45	1653	1608
1 S	"			21	4	1203	1126
2 N	"	92	100	42	36	1985	1938
2 S	"			47	35	1532	1470
3 N	"	80	83	30	28	1286	1208
3 S	"			40	33	2263	2195
4 N	"	92	88	38	17	1713	1617
4 S	"			36	50	1719	1669
5 N	"	98	100	45	48	1811	1755
5 S	"			9	3	1801	1732
Total for Contract No. 63				346	299	16966	16318
6 N	15 ft.	86	85	0	72	1182	1143
6 S	"			47	47	1534	1519
7 N	"	94	91	42	42	1011	990
7 S	"			0	0	870	855
8 N	"	95	93	5	5	1150	1111
8 S	"			5	0	1225	1182
9 N	"	87	81	45	36	879	858
9 S	"			8	35	890	866
10 N	"	131	120	47	38	1219	1166
10 S	14 ft.			33	44	1767	1731
11 N	"	85	89	24	30	951	927
11 S	"			43	43	977	962
12 N	"	112	103	63	52	1286	1194
12 S	"			31	35	1582	1533
Total for Contract No. 65				393	489	16523	16037

CONTRACT NO. 66

Completed March 4, 1913

Shaft.	Tunnel Diameter.	Previous Record Week's Work Combined Headings.		For the Week.		To Date.	
		Heading.	Comp. Tunnel.	Heading.	Bench.	Heading.	Bench.
19 N	12 ft.	136	131	60	47	1093	1012
19 S	"			60	63	1069	1008
20 N	"	135	133	88	74	850	781
20 S	"			80	79	849	836
21 N	11 ft.	46	23	0	0	25	0
21 S	"			0	0	21	0
22 N	"	155*	155*	60	60	1288	1278
22 S	"			65	65	1228	1218
23	"	86	86	37	38	1978	1964
24	"	71	72	Compl	eted	1732	1732
Total for Contract No. 67..........				450	426	10133	9829

THIS WEEK:

Record progress: D. Watts, Supt. No. 20, 168 ft. in two headings.
" " " 161 ft. completed tunnel two hdgs.
" " " 88 ft. in one heading.
" " " 81 ft. completed tunnel one hdg.

* L. Dennis, Supt.

Tunneling Progress, City Aqueduct. To give an adequate idea of the amount and progress of tunneling in the various headings of the City aqueduct, two weekly reports of progress are here given. Copies of these reports were given to the superintendents at the various shafts and a good deal of friendly rivalry was thereby stimulated. It will be seen that the best records were held by Contract 66 until near the completion of their tunneling, but these records were later exceeded on Contract 67, which to date (April, 1913) holds all the tunneling record on the City aqueduct. It is well to note that the rock on Contract 63 is hard Fordham and Yonkers gneiss and several headings were in bad ground; on Contract 65 the rock is Fordham gneiss to Shaft 7, below that mostly Manhattan schist. On Contract 66, Manhattan schist alone is found. On Contract 67 Manhattan schist is found at Shaft 19. At Shaft 20, mostly Inwood limestone, in appearance a coarse-grained marble; also Fordham gneiss. At Shafts 21, 22, 23, and 24, Granodiorite, a rock varying from medium to very hard and rather blocky at times, is found.

DATA ON SHAFT SINKING IN ROCK

(From time of starting shaft in rock to time of turning head.)

CITY TUNNEL—CATSKILL AQUEDUCT, DECEMBER, 1912

Shaft.	Depth in Rock.	Yards per Foot.	No. of Months Excavating and Lining.	Average Excavation per Month.*	Maximum Excavation per Month.	No. Feet Concreted.	Maximum Water G.P.M.	Average Water G.P.M.	Kind of Rock.	Drills Used.
1	233	8.4	7.5	32	60	168	39	22	Yonkers gneiss	Ing.-Rand. piston 3⅝″
2	197	8.6	7.5	28	67	74	60	15	do.	do.
3	169	11.8	6	29	81	145	16	12	Fordham gneiss	Ing.-Rand., piston 3¼″†
4	222	8.6	5.5	40	92	186	120	29	do.	Ing.-Rand., piston 3⅝″
5	197	8.6	6	33	60	40	28	17	do.	do.
6	253	8.6	8.5	31	68	216	8	2	do.	Electric, hand and Jap drills
7	275	8.6	11.5	25	89	199	25	5	do.	Jap
8	453	8.6	11.5	40	107	80	10	2	Manh. schist	Electric & Jap
9	418	8.6	12.5	34	73	295	10	3	do.	Electric‡
10	375	8.6	6.5	60	85	234	10	4	do.	Pneumelectric rotary Japs[c]
11	400	10.7	10	43	93	176	7	3	do.	Pneumelectric
12	235	8.6	7.7	32	66	129	3	2	do.	Jap
13	232	14.6	5.9	39.4	70	0	147	23	do.	Piston, Ing.-Rand., 3⅝″§
14	220	8.7	2.7	81.4	112	88	0	0	do.	do.
15	195	8.7	2.8	69.7	78	90	10	4	do.	do.
16	204	8.7	2.5	81.7	100	90	0	0	do.	Piston, Ingersoll, 3⅝″
17	176	8.7	3.3	53.3	65	115	5	3	do.	do.
18	156	14.6	3.6	43.3	47	0	21	17	do.	do.
19	640	8.9	7.9	81.1	109	612	1	1	do.	Rotary Jap
20	612	8.8	7.8	78.5	112	582	40	5	Fordham gneiss	do.
21	714	17.9	14.5	49.2	110	695	150	23	Grano-diorite	Piston, McKiernan ‖
22	586	8.7	8.5	69.0	103	562	17	6	do.	Piston, tripod, I-R. 3⅝″ ¶
23	162	11.8	2.3	70.5	77	143	8	4		do.
24	193	11.8	4.9	39.4	59	174	240	70	do.	do.

* This includes the lining of shaft, the total number of feet concreted being shown in a following column.

Usually work went on for 3 8-hour shifts for 6 days each week.

Shafts 13, 18, and 21 are irregular in shape. Other shafts are circular.

Shafts 13 and 18 are timbered.

† Tripods. ‡ Dulles-Baldwin. § Top only.

‖ 4′ 9½″ steel riser placed with lining.

¶ Stop of three weeks to turn south heading.

TABLES

APPROXIMATE WAGES PAID FOR EIGHT HOURS' WORK ON CATSKILL AQUEDUCT *

Cut-and-Cover.	Rate.
	Per Month.
Steam shovel man.....	$125
Steam shovel cranesman	75 to 90
Dinkey runner	90
Locomotive cranesman.	100
	Per Day.
General laborers, excavation and concrete..	1.60 to 1.75
Driller...............	3.00
Helper...............	2.25

Tunnels Outside City.	Rate.
	Per Day.
Drill runner..........	$3.00
Drill runner's helpers..	2.00
Muckers	1.75
Concrete laborers......	1.75 to 2.00
Hoist runners.........	3.00

Tunnels in City.	Rate.
	Per Day.
Drillers............	$3.75
Driller's helpers.....	2.00
Muckers and laborers	2.00
Muck boss..........	3.00 to 3.50
Pipeman...........	3.00
Pipeman helpers.....	2.00 to 2.50
Motormen..........	3.00
Compressor engineer.	4.80
Hoist runner........	4.25
Blacksmiths........	3.75
Carpenters.........	3.00
Heading Boss.......	4.50

Average pay† of men in cut-and-cover, $2.00 per day (about).
Average pay tunnel men outside of city, $2.25 per day (about).
Average pay tunnel men in city, $2.50 per day (about).

* This table is unofficial, wages varying with locality and year.
† Total pay roll divided by number of men.

CONTRACT 12—PROGRESS IN SINKING SHAFTS

(Monthly Averages in Various Rocks

Average Monthly Progress (Ft. per month)

Material Penetrated.	Downtake Shaft No. 1 (Circular).	Construction Shaft No. 2 (Rectangular).	Construction Shaft No. 3 (Rectangular).	Construction Shaft No. 4 (Rectangular).	Drainage Shaft No. 5 (Circular).	Construction Shaft No. 6 (Rectangular).	Construction Shaft No. 7 (Rectangular).	Uptake Shaft No. 8 (Circular).
Drift	$26\frac{1}{4}'$	$23\frac{1}{2}'$	$12\frac{1}{2}'$	90′	18′	45′	$43\frac{3}{4}'$	$33\frac{3}{8}'$
Hamilton shale	$87\frac{1}{2}'$							
Onondaga limestone	....	$89\frac{1}{3}'$						
Esopus shale	....	$73\frac{1}{2}'$	71′					
Helderberg limestone	....	....	$56\frac{3}{5}'$	$54\frac{1}{3}'$				
Binnewater sandstone	....	....	....	$38'(7\frac{1}{2})$*				
High Falls shale	....	....	....	$33'(18\frac{1}{2})$*	....	....	$52\frac{1}{4}'$	
Shawangunk grit	....	....	....	$45\frac{3}{5}'$	$49\frac{3}{4}'$	$62\frac{1}{3}'$	47′	$56\frac{1}{2}'$
Hudson River shale	....	....	....	....	77′	$78\frac{1}{3}'$	52′	56′ Above grit; $59\frac{1}{2}'$ Below grit

Average Monthly Progress

Circular shafts in Shawangunk grit	51′
Rectangular shafts in Shawangunk grit	52′
All shafts in Shawangunk grit	51.8′
All circular shafts	56′
All rectangular shafts (excluding shaft 4)	57′
All shafts (excluding Shaft 4)	$56\frac{1}{2}'$
All shafts in earth	$26\frac{1}{2}'$
Average shaft 4 excluding delays	$45\frac{1}{2}'$
Circular shafts in Hudson River shale	65′
Rectangular shafts in Hudson River shale	67′
All shafts in Hudson River shale	66′
Circular Shafts in Hamilton shale	$87\frac{1}{2}'$
Rectangular shafts in Esopus shale	73′
Rectangular shafts in Helderberg limestone	55′
Rectangular shafts in High Falls shale	40′
Average time in setting up head frames, etc, 3 weeks	

* Average Monthly Progress in Shaft 4, including delays when Shaft was flooded.

BOARD OF WATER SUPPLY, CITY OF NEW YORK

List of Contracts, March 15, 1912

No.	Description.	Contractor's Home Address.	Contractor's Field Address.	Amount of Contract.
2	Portion of Peekskill division, Westchester and Putnam Cos., N. Y.	Thos. McNally Co., Pittsburgh, Pa. (Receivers, B. B. Odell, Jr. and W. E. Paine, 16 Beaver St., N. Y. C.)	Peekskill, N. Y.	$4,126,423.00
3	Main dams, Ashokan reservoir, Ulster Co., N. Y.	MacArthur Bros. Co. and Winston & Co., 11 Pine St., N. Y. C.	Brown's Station, N. Y.	12,669,775.00
9	Kensico dam and appurtenant works, Westchester Co., N. Y.	H. S. Kerbaugh, Inc., Land Title Bldg., Philadelphia, Pa., and 65 Pine St., N. Y. C.	Valhalla, N. Y.	7,953,050.00
10	Headworks of Catskill Aqueduct, near Brown's Station, Ulster Co., N. Y.	Jules Breuchaud, 290 Broadway, N. Y. C.	Brown's Station, N. Y.	1,146,600.00
11	Esopus cut-and-cover and Peak tunnel, Ulster Co., N. Y.	Stewart-Kerbaugh-Shanley Co., 527 5th Ave., N. Y. C.	Atwood, N. Y.	2,368,920.00
12	Rondout siphon and north half of Bonticou tunnel, Ulster Co., N. Y.	The T. A. Gillespie Company, 50 Church St., N. Y. C.	High Falls, N. Y.	6,290,803.50
15	Wallkill south cut-and-cover, Ulster Co., N. Y.	The Elmore & Hamilton Contg. Co., 56 Tweddle Bldg., Albany, N. Y. (Receivers, Augustus N. Hand and Stephen L. Selden, 49 Wall St., N. Y. C)	Gardiner, N. Y.	933,867.50
16	Part of St. Elmo cut-and-cover, Ulster Co., N. Y.	King, Rice & Ganey Co., 280 Broadway, N. Y. C.	Wallkill, N. Y.	610,407.50
17 & 18	St. Elmo siphon and portions of St. Elmo and Orange cut-and-cover, Ulster and Orange Cos., N. Y.	American Pipe and Construction Co., 112 N. Broad St., Philadelphia, Pa.	St. Andrew, N. Y. (Walden P. O.)	722,510.00 836,185.00
20	Moodna siphon, Orange Co., N. Y.	Mason & Hanger Co., Cornwall-on-Hudson, N. Y.	Cornwall-on-Hudson, N. Y.	3,492,511.00
22	Bull Hill tunnel and cut and-cover, Putnam Co., N. Y.	Patterson & Co., Pittsburgh, Pa. (Receivers, James G. Shaw and Benjamin Barker, 115 Broadway, N. Y. C.)	Cold Spring, N. Y.	824,942.50
23	Hunter's Brook and Scribner tunnels and cut-and-cover, Westchester Co., N. Y.	Glyndon Contracting Co., Yorktown Heights, N. Y.	Yorktown Heights, N. Y.	1,109,102.50
24	Croton Lake siphon, Turkey Mt. tunnel and cut-and-cover, Westchester Co., N. Y.	Bradley Contracting Co., 1 Madison Ave., N. Y. C.	Croton Lake, N. Y.	973,694.50
25	Croton and Chadeayne tunnels and cut-and-cover, Westchester Co., N. Y.	Chas. W. Blakeslee & Sons, New Haven, Conn.	Kitchawan, N. Y.	1,269,830.00
30	Hill View reservoir and portions of Yonkers and Van Cortlandt siphons, Westchester Co., N. Y.	Keystone State Const. Co., 704 Pennsylvania Bldg., Philadelphia, Pa.	Central and Shipman Aves., Yonkers, N. Y.	3,269,280.00

31	Four controlling valves and appurtenances, Ashokan reservoir, Ulster Co., N. Y.	Ogden Iron & Steel Mfg. Co., 147 Cedar St., N. Y. C.		54,900.00
39	Pumping plant at Jerome Avenue Pumping Station, Borough of The Bronx, N. Y. C.	Lord Electric Co., 105 W. 40th St., N. Y. C.		34,884.00
41	Twenty sluice-gates, stop-disks, etc., Ashokan and Hill View reservoirs	Ogden Iron & Steel Mfg. Co., 147 Cedar St., N. Y. C.		90,670.00
42	Sluice-gates, gate-valves, etc., at Ashokan reservoir and Croton Lake siphon	Coffin Valve Co., Boston, Mass.		151,749.00
43	Gate-valves, sluice-gates, etc., Ashokan, Kensico and Hill View reservoirs and along Catskill aqueduct	Coffin Valve Co., Boston, Mass.		69,444.25
44	Sluice-gates, etc., at Ashokan, Kensico and Hill View reservoirs and steel pipe siphons	Coldwell-Wilcox Company, Newburgh, N. Y.		187,578.00
45	South portion of Orange cut-and-cover, Orange Co., N. Y.	Pittsburgh Contracting Co., 1942 Forbes St., Pittsburgh, Pa.	R. F. D. No. 4, Newburgh, N. Y.	1,675,290.00
47	Wallkill siphon, half of Bonticou tunnel, etc., Ulster Co., N. Y.	The Degnon Contracting Co., 60 Wall St., N. Y. C.	Forest Glen Sta., N. Y.	4,982,726.00
48	Remainder of Kingston sewer, Ulster Co., N. Y.	King, Rice & Gancy Co., 280 Broadway, N.Y.C.	Kingston, N. Y.	146,631.00
49	Six reinforced concrete bridges at Ashokan reservoir, Ulster Co., N. Y.	Harrison & Burton, 220 Broadway, N. Y. C.	West Shokan, N. Y.	248,222.50
52	Eastview and Elmsford tunnels and cut-an-cover, Westchester Co., N. Y.	Pittsburgh Contracting Co., 1942 Forbes St., Pittsburgh, Pa.	Elmsford, N. Y.	2,205,852.50
53	Ardsley and Grassy Sprain cut-and-cover and Platt Ave. siphon, Westchester Co., N. Y.	The Elmore & Hamilton Contg. Co., 56 Tweddle Bldg., Albany, N. Y. (Receivers, Augustus N. Hand and Stephen L. Selden, 49 Wall St., N. Y. C.)	Ardsley, N. Y.	1,485,150.00
54	Portion of Yonkers siphon, Westchester Co., N. Y.	Geo. W. Jackson, Inc., 46 Wall St., N. Y. C., and Chicago, Ill.	Seminary Ave., near Mile Sq. Road, Yonkers, N. Y.	1,479,425.00
55	Portions of aqueduct in Croton and Kensico divisions and Kensico influent, effluent and aeration structures	Rinehart & Dennis Co., Charlottesville, Va.	Gibson, N. Y.	4,545,487.50
56	Power plant for gate operation and lighting, Ashokan reservoir			
57	Power plant for gate operation and lighting, Kensico reservoir			
58	Drainage equipment for Rondout siphon	D'Olier Eng. Co., Morris Bldg., Philadelphia, Pa.		46,685.00
59	Highways and appurtenances, Ashokan reservoir, Ulster Co., N. Y.	The C. P. Bower Construction Co., Bulletin Bldg., Philadelphia, Pa.	Ashton, N. Y.	323,861.00
60	Hurley dikes for Ashokan reservoir, Ulster Co., N.Y.	MacArthur Bros. Co., 11 Pine St., N. Y. C.	West Hurley, N. Y.	971,275.00
61	Wallkill blow-off			
62	Seven steel pipe siphons in Ulster, Putnam and Westchester Cos., N. Y.	The Snare & Triest Co., 143 Liberty St., N.Y.C.		1,643,365.00

BOARD OF WATER SUPPLY, CITY OF NEW YORK

Continued.

No.	Description.	Contractor's Home Address.	Contractor's Field Address.	Amount of Contract.
63	City tunnel, City line to Aqueduct and Burnside Aves, N. Y. C.	Mason & Hanger Co., Van Cortlandt Park, N. Y. C.	Van Cortlandt Park, N. Y. C.	$3,706,372.00
65	City tunnel, Aqueduct and Burnside Aves. to Central Park at W. 99th St., N. Y. C.	Pittsburgh Contracting Co., 1942 Forbes St., Pittsburgh, Pa.	3785 Broadway, N. Y. C.	5,590,225.00
66	City tunnel, Central Park at W. 99th St. to Union Square at 14th St., N. Y. C.	Grant Smith & Company & Locher, 25 W. 42d St., N. Y. C.	25 W. 42d St., N. Y. C.	4,512,605.00
67	City tunnel, Union Square at 14th St. to 3d Ave. and Schermerhorn St. and to Ft. Greene Park, Brooklyn	Holbrook, Cabot & Rollins Corp., Geo. B. Fry and Thos. B. Bryson, 331 Madison Ave., N. Y. C.	331 Madison Ave., N. Y. C.	5,272,435.00
68	Seven steel pipe siphons in Westchester Co., N. Y.	The T. A. Gillespie Co., 50 Church St., N. Y. C.	Tuckahoe Road, Yonkers, N. Y.	1,189,557.50
69	Racks for siphon and gate chambers			
70	Bronze gate-valves for city tunnel			
71	Macadamizing highways and paving top of Olive Bridge dam			
72	Clearing and grubbing Ashokan reservoir	J. F. Cogan Company, Contractors, 280 Broadway, N. Y. C.		451,000.00
75	Bay Ridge conduit, Brooklyn, N. Y.	F. V. Smith & Son, Inc., Turnbull Ave. and Westchester Creek, N. Y. C.		237,000.00
76	Dividing Weir bridge, Ashokan reservoir			
77	Wakefield Ave. blow-off, Westchester Co.	Geo. L. Brown and T. J. Brown, 87 Hamilton Place, N. Y. C.		58,178.25
79	Blow-offs from Elmsford and Bryn Mawr siphons			
80	Breakneck tunnels, Dutchess and Putnam Cos., N. Y.	The Dravo Contracting Co., 814 Lewis Block, Pittsburgh, Pa.	Storm King, N. Y.	456,515.00
84	Furnishing bronze shaft caps for City tunnel			
86	Part of Queens conduit, Queens Borough, N. Y. C.			
87	Brooklyn conduit, Brooklyn, N. Y.	Wm. F. Donovan and Charles Cranford, 186 Remsen St., Brooklyn, N. Y.	376 9th St., Brooklyn N. Y.	366,014.70
88	Richmond conduit, Staten Island, N. Y.			
89	Silver Lake reservoir			
90	Completion of Hudson siphon, Orange and Dutchess Cos.	The T. A. Gillespie Company, 50 Church St., N. Y. C.	Cornwall-on-Hudson	1,649,020.00
91	Appurtenances for screen and gate chambers and aerators			
92	Gauging, metering and other apparatus			
93	Power transmission and telephone lines			

94	Steel floats for drainage shafts			
95	Cranes for gate chambers			
99	Furnishing and laying pipe for Narrows siphon			
100	Extension of Croton blow-off into Croton lake	Stobaugh Contracting Co., 1 Madison Ave., N. Y. C	Croton Lake, N. Y	41,572.50
101	Fences at reservoirs and along portions of Catskill Aqueduct			
103	Part of Queens conduit, Queens Borough, N. Y. C.	Beaver Engineering & Contracting Co., 182 Broadway, N. Y. C	Martin St. and Flushing Ave., Maspeth, L. I	344,053.00
104	Iron gate and iron control valves			
105	Bronze stop, gate, section and riser valves for City tunnel			
106	Aeration nozzles, Ashokan and Kensico reservoirs.			
107	Valves for Wallkill and Hudson blow-offs and City pipe lines	The Chapman Valve Mfg. Co., Indian Orchard, Mass		121,629.50
109	Breakneck gauging chamber and chambers for Foundry brook and Indian brook siphons			
110	Gauging, metering and other apparatus			
111	Three bridges, Ashokan reservoir			
112	Ladders, gratings and other metal fittings, Ashokan reservoir			
113	Test-pits and borings at site of Silver Lake reservoir	Sweeney & Gray Co., 81 6th St., Long Island City, N. Y		4,745.00
114	Regulating valves for City tunnel and pipe lines	Coffin Valve Co., Neponset, Boston, Mass		13,405.00
115	Esopus pumping station			
116	Machinery and transmission line for Esopus pumping station			
117–129	Reserved for superstructures			
130	Reinforced concrete tiles for superstructures			
131	Landing stage; grading and excavation at Hudson drainage shaft			
132	Borings at and near the site of Silver Lake reservoir			

CATSKILL AQUEDUCT

MONTHLY PROGRESS OF SHAFT SINKING—E = Excavation. T = Timbering. L = Lining.

Tunnel.	Shaft No.		Feet per Month.	Depth, Feet. Earth.	Depth, Feet. Rock.	Depth, Feet. Total.	Sta-ted.	Completed
Rondout	1	E, T	22, 22—0, 0—34, 34*—55, 28*—48, 72—116, 59—118, 118—138, 132,—62, 107—3, 0	84	509	593	Aug., 1908	May, 1909
	2	E, T	14, 14*—55, 40*—79, 70—96, 56—99, 106—95, 132—8, 0	56	390	446	Sept., 1908	Mar., 1909
	3	E, T	6, 0—65, 10—73, 54—56, 104—44, 54—52, 52—68, 39, 10, 35	8	366	374	July, 1908	Feb., 1909
	4	E, T	10, 0—37, 0—50, 79—73, 71—64, 64—26, 0—0, 38—0, 0—0, 0—6, 0—39, 40—17, 0—0, 0—0, 0—44, 17—34, 77—65, 0—23, 61—9, 0	6	491	497	July, 1908	Jan., 1910
	5	E, T	2, 0—10, 12—0, 0—44, 38*—47, 0—31, 61—50, 50—62, 65—59, 0—88, 87—76, 132—28, 53	50	447	497	July, 1908	June, 1909
	6	E, T	15, 0—32, 0—50, 27—69, 110—78, 55—67, 109—101, 79—82, 56—33, 58	27	500	527	July, 1908	Mar., 1909
	7	E, T	15, 0—46, 0—47, 80—40, 0—55, 57—37, 51—43, 57—53, 53—87, 70—69, 89—13, 27—9, 0	35	479	514	July, 1908	June, 1909
	8	E, T	7, 0,—37, 0—77, 94—54, 0—51, 70—31, 64—71, 86—80, 56—83, 60—69, 76—75, 106—62, 79—13, 0	42	668	710	July, 1908	July, 1909
Wallkill	1	E, L	20, 0—110, 0—60, 115—89, 52—94, 80—80, 89—27, 81—3, 0—0, 3	9	474	483	June, 1909	Feb., 1910
	2	E, T, L	33, 0, 33—18, 0, 18—15, 2, 13—51, 20, 0—72, 87, 0—97, 59, 0—72, 62, 0	74	284	358	July, 1909	Jan., 1910
	3	E, L	14, 0—34, 0—35, 21—58, 47—74, 107—93, 61—56, 51—9, 24	58	315	373	May, 1909	Dec., 1909
	4	E, T	35, 12—63, 38—76, 86—58, 49—71, 100—53, 5—0, 35	11	345	356	May, 1909	Nov., 1909
	5	E, T	12, 12—10, 10—30, 19—34, 38—91, 48—69, 111—81, 48—19, 29	42	308	350	May, 1909	Dec., 1909
	6	E, L	31, 0—40, 0—18, 10—62, 41—50, 91—77, 40—35, 75—77, 0—13, 0—0, 84—0, 7	55	348	403	May, 1909	Mar., 1910

Moodna	1	E, T, L	27, 27, 0—49, 43, 10—35, 23, 83—74, 43, 12—18, 0, 72—110, 8, 0—46, 0, 133—166, 0, 0—60, 0, 179—1, 0, 50..	145	441	586	Aug., 1909	May, 1910
	2	E, T, L	44, 0, 44—65, 42, 5—65, 50, 0—60, 69, 0—63, 47, 0—68, 89, 0—86, 79, 0—36, 31, 0—0, 31, 0..................	101	386	487	Sept., 1909	May, 1910
	3	E, T	14, 14—51, 34—42, 35—47, 56—60, 30—55, 81—51, 45—22, 19—0, 28....................................	0	342	342	Aug., 1909	April, 1910
	4	E, T	14, 0—68, 45—75, 61—80, 102—68, 76—89, 88—9, 30...	37	366	403	Aug., 1909	Feb., 1910
	5	E, T	26, 9—71, 21—56, 36—65, 115—82, 72—78, 72—46, 76—7, 0—0, 31..	2	430	432	Aug., 1909	April, 1910
	6	E, T	82, 53—86, 79—75, 80—78, 0—56, 83—75, 68—55, 83—30, 52—0, 0—0, 39................................	6	531	537	Aug., 1909	May, 1910
	7	E, T	3, 0—59, 23—22, 31—58, 0—61, 73—49, 94—75, 0—46, 102—0, 0—0, 50....................................	15	358	373	Jan., 1910	Oct., 1910
Hudson River	East	E, T	48, 0—53, 0—54, 81—39, 71—23, 0—38, 0—21, 55—2, 33. Resumed 1909 in Feb.—6, 0—8, 0—16, 0—22, 52—49, 0—19, 56—36, 0—8, 64—64, 0—54, 74—57, 72—57, 0—39, 77—62, 40—34, 85—28, 0—51, 49—44, 62—53, 0—28, 73—39, 38—34, 60—52, 25—10, 37—25, 28—12, 38	8	1179	1187	May, 1907	Mar., 1911
	West	E, T	36, 0—59, 48—52, 52—45, 41—32, 46—16, 0—21, 0—6, 32. Resumed in 1909 in June—31, 0—21, 97—67, 0—36, 74—18, 0—35, 57—69, 0—39, 98—53, 0—58, 80—53, 0—54, 80—30, 70—32, 0—20, 72—33, 48—39, 49—51, 52—56, 64—56, 87—27, 24—8, 4—0, 4..................	7	1146	1153	Mar., 1907	April, 1911
Breakneck	Uptake	E, L	83, 0—23, 73—7, 17—158, 3—1, 84—138, 74—145, 0—34, 234—0, 76....................................	0	589	589	Oct., 1910	June, 1911
Garrison	Pump	E, T	32, 32—29, 29....................................	40	21	61	July, 1908	Aug., 1908
	North	E, T	42, 42—42, 42—11, 11..............................	95	10	105	Aug., 1908	Oct., 1908
	Main	E, T	12, 10—29, 0—22, 0—31, 10—22, 80—31, 26—28, 27......	6	181	187	June, 1907	Dec., 1907

* Concrete caisson.

CATSKILL AQUEDUCT—*Continued*

Monthly Progress of Shaft Sinking—E = Excavation. T = Timbering. L = Lining.

Tunnel.	Shaft No.		Feet per Month.	Depth, Feet. Earth.	Rock.	Total.	Started.	Completed.
Croton Lake	Down-take	E, L	20, 0—43, 0—65, 0—80, 0—65, 0—15, 0—0, 0—0, 0—0, 0—0, 49—15, 35—43, 14—52, 6—81, 0—13, 0—12, 0—39, 0	0	542	542	Aug., 1909	Dec., 1910
	Uptake	E, L,	85, 0—85, 0—8, 60—0, 93—68, 5—19, 0—0, 0—0, 0—45, 0—82, 0—74, 0—39, 0—2, 0—0, 220—0, 102	0	505	505	Aug., 1909	Oct., 1910
Yonkers	1	E	30, 64, 51, 9, 1	1	154	155	May, 1910	Sept., 1910
	2	E	33, 32, 35, 6	9	97	106	May, 1910	Aug., 1910
	3	E	25, 34, 40, 17	5	111	116	May, 1910	Aug., 1910
Hillview	Uptake	E, T	7, 0—43, 50—67, 21—20, 0—6, 0	72	71	143	Mar., 1910	July, 1910
	Down-take	E, T	5, 0—61, 65—71, 0—96, 0—71, 0	67	244	311	Mar., 1910	July, 1910
New York City	1	E, L	4, 0—31, 0—30, 40—49, 0—63, 0—12, 128—3, 0—36, 0—9, 0—3, 0—5, 29	5	240	245	July, 1911	May, 1912
	2	E, L	10, 0—45, 0—53, 0—25, 74—65, 0—16, 0—3, 0—9, 83—2, 0	6	222	228	Aug., 1911	April, 1912
	3	E, L	10, 0—25, 0—33, 0—55, 0—70, 76—22, 51—3, 0	2	216	218	July, 1911	Jan., 1912
	4	E, L	12, 0—75, 0—62, 92—32, 0—30, 0—3, 0—28, 69	14	228	242	Aug., 1911	Feb., 1912
	5	E, L	15, 0—33, 0—47, 0—56, 40—7, 0—62, 0—0, 129	31	195	226	Aug., 1911	Mar., 1912
	6	E, L	5, 0—12, 0—17, 0—47, 0—25, 54—3, 18—59, 0—27, 0—52, 0—31, 120—0, 0—0, 26	3	275	278	June, 1911	May, 1912
	7	E, L	15, 0—16, 12—25, 19—50, 16—32, 0—21, 57—80, 0—4, 78—76, 0—28, 0—7, 0—0, 50—0, 63	65	287	352	Sept., 1911	Sept., 1912
	8	E, L	7, 0—10, 0—4, 0—20, 0—55, 0—34, 0—71, 80—45, 0—90, 0—107, 0—33, 110—0, 221—0, 0—0, 0—2, 0	17	461	478	June, 1911	Aug., 1912

New York City	9	E, L	8, 0—8, 0—4, 0—40, 0—61, 5—19, 115—30, 20—37, 0—66, 0—50, 34—35, 121—73, 0—4, 0—4, 0—2, 3—0, 107.....	15	426	441	June, 1911	Sept., 1912
	10	E, L	10, 0—28, 0—66, 0—54, 72—110, 7—8, 65—61, 62—68, 0—0, 0—0, 127—0, 2........	12	393	405	Aug., 1911	June, 1912
	11	E, L	15, 0—19, 0—63, 0—48, 55—66, 18—17, 2—23, 99—94, 0—70, 0—2, 0—0, 197—32, 9—0, 17........	8	441	449	Aug., 1911	Aug., 1912
	12	E, L	6, 0—19, 0—45, 10—28, 55—15, 7—43, 47—78, 0—28, 0—0, 0—0, 100........	3	259	262	Aug., 1911	June, 1912
	13	E, T	8, 0—7, 0—49, 0—52, 35—59, 108—32, 0—25, 28—21, 0—0, 42........	16	237	253	Aug., 1911	April, 1912
	14	E, L	9, 0—9, 0—28, 0—78, 65—85, 23—31, 0—0, 100........	20	220	240	July, 1911	Jan., 1912
	15	E, L	7, 0—1, 0—18, 0, —76, 0—73, 90—46, 45—0, 24........	23	198	221	July, 1911	Jan., 1912
	16	E, L	28, 0—51, 45—90, 45—49, 80........	14	204	218	Oct., 1911	Jan., 1912
	17	E, L	40, 0—51, 0—22, 75—61, 40—45, 0—4, 45........	40	183	223	Aug., 1911	Jan., 1912
	18	E, T	11, 0—25, 18—33, 26—39, 39—51, 47—42, 18—4, 32.....	41	164	205	July, 1911	Jan., 1912
	19*	E, L	23, 0—15, 45—30, 0—0, 0—60, 0—65, 89—71, 82—96, 81—68, 91—90, 51—108, 102—80, 106—4, 0........	69	641	710	Aug., 1911	Aug., 1912
	20*	E, L	23, 0—10, 72—69, 33—24, 0—0, 0—44, 0—116, 57—38, 117—77, 76—56, 30—63, 72—91, 85—108, 52—25, 81—5, 0.	126	623	749	Sept., 1911	Nov., 1912
	21*	E, L	5, 0—4, 0—0, 0—12, 0—34, 0—35, 0—90, 0—27, 80—26, 93—72, 89—76, 50—81, 41—33, 92—57, 41—39, 69—63, 30—54, 54—14, 38—35, 61........	43	714	757	Sept., 1911	Mar., 1913
	22*	E, L	10, 0—16, 0—31, 81—62, 19—3, 0—0, 0—75, 0—76, 37—70, 65—20, 0—51, 127—79, 111—98, 41—72, 112—54, 66...	121	596	717	July, 1911	Sept., 1912
	23*	E, L	16, 0—28, 0—24, 123—29, 0—47, 0—0, 0—84, 0—35, 89—49, 0—6, 40........	150	168	318	Oct., 1911	July, 1912
	24*	E, L	10, 0—21, 0—27, 78—60, 27—10, 0—0, 0—33, 0—61, 19—46, 38—15, 0—23, 78—18, 10—5, 12........	128	201	329	July, 1911	July, 1912

* Caisson through earth.

CATSKILL AQUEDUCT

Monthly Progress of Grade Tunnel Excavation

Tunnel.	Heading.	Average of Heading and Bench Advance. Feet per Month.	Length of Tunnel, Feet.	Date Started.	Date Completed.
Peak	N	107, 248, 209, 167, 266, 281, 250, 75	1603	April, 1909	Nov., 1909
	S	15, 106, 215, 267, 229, 382, 289, 292, 39	1834	Mar., 1909	Nov., 1909
Bonticou	N	105, 271, 296. 217, 310, 269, 350, 380, 425, 410, 269, 38	3340	Nov., 1908	Oct., 1909
	S	3, 89, 243, 237, 316, 308, 334, 301, 339, 286, 270, 283, 201, 205, 10	3450	Sept., 1909	Nov., 1910
Mohonk	N	15, 115, 130, 19	279	Nov., 1911	Feb., 1912
	S	33, 117, 131	281	Jan., 1911	Mar., 1911
Breakneck	N	44, 37, 31, 0, 68, 25	205	Oct., 1910	Mar., 1911
	S	32, 107, 95, 110, 138, 246, 121	849	Oct., 1910	April, 1911
Bull Hill	N	22, 64, 106, 170, 159, 192, 203, 168, 186, 184, 192, 174, 161, 109, 168, 192, 169, 25	2644	Aug., 1909	Jan., 1911
	S	61, 209, 220, 196, 226, 198, 210, 172, 150, 208, 156, 191, 182, 178, 164	2721	July, 1909	Sept., 1910
Mekeel	N	75, 108, 104, 68, 91, 70, 82, 64, 64, 61, 50, 53, 8, 0, 0, 2	900	Sept., 1909	Dec., 1910
Garrison	N. portal	10, 18, 22, 9, 6, 12, 18, 46, 18, 7, 0, 0, 0, 0, 10—Dec., 1911—20, 58, 63	317	Aug., 1907	Feb., 1912
	N. shaft N.	14, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 5, 0, 4—Resumed April, 1911—14, 53, 58, 42, 48, 55, 42, 28	363	Oct., 1908	Nov., 1911
	N. shaft S.	3, 0, 0, 0, 0, 0, 0, 0, 0, 0, 5, 6, 16, 22, 52, 141, 66, 136, 0, 0, 0, 0, 33, 115, 161, 237, 143, 57, 199, 138, 193, 211, 195, 162, 213, 206, 122	2832	Oct., 1908	Oct., 1911
	Main Shaft N.	10, 10, 19, 0, 24, 52, 90, 121, 107, 106, 51, 0, 0, 0, 0, 0, 0, 0, 0, 56, 161, 161, 76, 97, 100, 124, 0, 0, 0, 0, 0, 85, 147, 3, 0, 81, 220, 129, 146, 180, 161, 26	2543	Jan., 1908	July, 1911

Garrison	Main Shaft S.	11, 11, 2, 28, 6, 36, 78, 132, 104, 107, 42, 55, 140, 179, 121, 160, 139, 160, 0, 0, 0, 0, 94, 163, 126, 3, 0, 68, 163, 169, 208, 167, 138, 126, 211, 150, 0, 0, 46, 57, 145, 64, 11	3620	Jan., 1908	April, 1912
	S. portal	21, 120, 150, 128, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 29, 190, 187, 198, 217, 91, 221, 175, 20, 6, 2	1755	Dec., 1909	Aug., 1912
Cat Hill	N	57, 64, 45, 33, 43, 45, 70, 50, 45, 74, 17, 0, 0, 0, 0, 0, 0, 0, 0, 51, 60, 85, 79, 93, 115, 83	1109	Jan., 1908	Feb., 1910
	S	60, 52, 52, 49, 33, 45, 73, 69, 49, 83, 2, 0, 0, 0, 0, 0, 0, 0, 0, 101, 55, 88, 82, 108, 155, 83, 58	1225	Jan., 1908	Mar., 1910
Hunters Brook	N	30, 98, 131, 27, 85, 91, 73, 85, 73, 111, 162, 222, 234, 160, 0, 3, 0, 77, 142, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 8	1812	Oct., 1909	Sept., 1912
	S	72, 85, 89, 172, 132, 116, 89, 63, 118, 195, 228, 220, 110, 23, 208, 241, 279, 263, 268, 259, 281, 251, 163, 215, 27, 3, 0, 7, 1, 0, 8, 53, 84, 14	4338	Dec., 1909	Sept., 1912
Scribner	S	11, 64, 103, 39, 83	300	Oct., 1909	Feb., 1910
Turkey Mountain	N	7, 0, 0, 0, 0, 23, 22, 49, 84, 0, 18, 76, 36	315	Dec., 1909	Dec., 1910
	S	20, 110, 122, 32, 0, 0, 93, 172, 177, 181, 117, 60	1085	Oct., 1909	Sept., 1910
Croton	S	3, 25, 134, 226, 238, 129, 154, 120, 142, 132, 142, 125, 104, 143, 107, 119, 120, 141, 156, 136, 141, 141, 113	2990	Aug., 1909	June, 1911
Chadeayne	N	66, 131, 85, 65, 113, 140, 76, 24	700	Nov., 1909	June, 1910
Millwood	N	10, 85, 78, 50, 82, 55, 95, 95, 93, 22, 30, 5, 25, 0, 14, 83, 110, 109, 79, 66, 60, 80, 45, 104, 66, 83, 94, 96, 81, 70, 80		June, 1910	
	S	117, 113, 113, 105, 93, 110, 95, 77, 95, 93, 120, 58, 40, 80, 105, 104, 93, 99, 113, 92, 112, 92, 106, 99, 52		June, 1910	
Sarles	N	75, 102, 105, 90, 115, 100, 73, 95, 62, 83, 35, 35, 86, 90, 97, 97, 91, 90, 75, 84, 77, 71, 81, 90, 93, 105, 78	2275	July, 1910	Sept., 1912
	S	121, 100, 93, 101, 101, 102, 107, 122, 120, 100, 115, 91, 109, 104, 100, 93, 20, 80, 90, 102, 100, 77, 112, 117, 107, 92, 110, 90, 100, 69	2955	April, 1910	Sept., 1912

CATSKILL AQUEDUCT—*Continued*

Tunnel.	Heading.	Average of Heading and Bench Adva ce. Feet per Month.	Length of Tunnel, Feet.	Date Started.	Date Completed.
Harlem R.R.	N	15, 43, 59, 52, 63, 83, 114, 121, 0, 0, 0, 13, 77, 73, 90, 82	885	June, 1910	Sept., 1911
	S	35, 76, 104, 15	115	Feb., 1911	April, 1911
Pleasant-ville	S	50	50	Oct., 1912	Oct., 1912
	N	47, 47, 66, 95, 49, 0, 0, 0, 44, 93, 91, 65, 0, 0, 0, 46, 6	650	Feb., 1911	June, 1912
Reynold's Hill	N	90, 114, 118, 128, 90		Aug., 1912	
	S	29, 46, 10, 5, 20, 52, 43, 102, 116, 102, 45, 46, 44, 22, 0, 0, 53, 72, 83, 80, 71, 90, 93, 183, 144, 132		Nov., 1910	
Lakehurst	N	115, 68, 117, 43, 122, 122, 135, 86, 30	788	May, 1910	Dec., 1910
	S	32, 124, 158, 191, 5, 45, 140, 130, 38	862	June, 1910	Feb , 1911
Dike	N	27, 0, 0, 74, 108, 99, 119, 92, 65, 64, 0, 0, 0, 50, 88, 30, 85, 100, 7	1008	Dec., 1910	Aug., 1912
	S	38, 105	143	Aug., 1912	Sept., 1912
Kensico	N	135, 122, 52, 0, 0, 0, 50, 28, 38, 116, 66, 0, 23	630	April, 1910	April, 1911
	S	72, 117, 101, 69, 72, 17, 0, 0, 0, 0, 47, 71, 75, 37, 118, 89	885	Mar., 1910	June, 1911
Eastview	N. portal	71, 229, 194, 232, 261, 248, 87, 240, 180, 136	1878	July, 1910	April, 1911
	Shaft N.	5, 43, 14, 36, 157, 91, 47, 18, 0, 0, 58, 87, 96, 75, 109, 108, 98, 121, 104, 88, 30	....	April, 1910	
	Shaft S	4, 45, 17, 64, 179, 225, 21, 0, 0, 0, 0, 0, 11, 73	639	April, 1910	May, 1911
	S. portal	17, 134, 180, 183, 220, 94, 63, 73, 141, 155, 96	1355	June, 1910	April, 1911
Elmsford, North	N	46, 80, 89, 79, 69, 1	364	Mar., 1912	Aug., 1912
	S	10, 35, 40, 77, 0, 43, 110, 136, 134, 170, 171, 160, 151, 190, 144, 68, 96, 104, 102, 48	2011	June, 1911	
Elmsford S.	N	2, 34, 54, 72, 77, 78, 64, 74, 20, 0, 0, 0, 61, 68, 52, 97, 91, 76, 31	950	May, 1911	Dec., 1912

CATSKILL AQUEDUCT

Monthly Progress of Pressure Tunnel Excavation

Tunnel.	Heading.	Average of Heading and Bench Advance. Feet per Month.	Length of Tunnel, Feet.	Date Started.	Date Completed.
Rondout	1S	46, 34, 0, 235, 282, 308, 311, 365, 207, 60	1848	April, 1909	Jan., 1910
	2N	65, 12, 155, 201, 218, 313, 295, 304, 187, 172, 98	2020	Mar., 1909	Jan., 1910
	2S	63, 15, 153, 198, 216, 322, 311, 311, 256, 82	1927	Mar., 1909	Dec., 1909
	3N	20, 69, 163, 221, 230, 263, 345, 338, 371, 348, 92	2460	Feb., 1909	Dec., 1909
	3S	24, 68, 161, 234, 227, 245, 269, 292, 306, 293, 68, 182, 123, 0, 0, 0, 0, 0, 16, 77, 182, 198, 93, 85, 0, 11, 14	3164	Feb., 1909	April, 1911
	4N	5, 40, 42, 27, 73, 116, 37, 3, 0, 9, 38, 44, 76, 114, 140, 117, 85, 14	976	Dec., 1909	May, 1911
	4S	5, 29, 61, 18, 82, 148, 143, 166, 174, 0, 7, 28, 50	911	Dec., 1909	Dec., 1910
	5N	19, 120, 326, 306, 100, 153, 225, 217, 174, 160, 34	1834	July, 1909	May, 1910
	5S	35, 136, 322, 339, 249	1081	July, 1909	Nov., 1909
	6N	9, 59, 187, 260, 283, 331, 296, 289, 400	2114	Mar., 1909	Nov., 1909
	6S	10, 57, 166, 272, 284, 315, 317, 280, 49	1750	Mar., 1909	Nov., 1909
	7N	63, 118, 260, 249, 249, 430, 71	1440	May, 1909	Nov., 1909
	7S	49, 111, 280, 264, 252, 400, 489, 52	1897	May, 1909	Dec., 1909
	8N	90, 12	102	July, 1909	Aug., 1909
Wallkill	1S	10, 76, 0, 6, 216, 321, 351, 333, 409, 247, 276, 355, 99	2700	Dec., 1909	Dec., 1910
	2N	85, 1, 62, 166, 216, 311, 322, 339, 364, 434, 77	2378	Feb., 1910	Dec., 1910
	2S	84, 4, 56, 154, 214, 240, 334, 361, 164	1611	Feb., 1910	Oct., 1910
	3N	18, 0, 100, 317, 274, 307, 384, 307, 370, 531, 129	2736	Dec., 1909	Oct., 1910
	3S	24, 0, 98, 311, 316, 357, 380, 334	1820	Dec., 1909	July, 1910
	4N	10, 69, 33, 260, 335, 379, 340, 352, 379, 337	2494	Oct., 1909	July, 1910
	4S	12, 73, 25, 254, 288, 368, 319, 254, 217, 172, 284, 32	2298	Oct., 1909	Sept., 1910
	5N	7, 55, 4, 41, 267, 358, 375, 369, 425, 189	2090	Dec., 1909	Sept., 1910
	5S	7, 41, 12, 52, 237, 351, 347, 355, 407, 395, 400, 283, 119	3006	Dec., 1909	Dec., 1910
	6N	57, 28, 0, 0, 119, 367, 299, 327, 344, 308, 259, 88	2195	Jan., 1910	Dec., 1910

CATSKILL AQUEDUCT—*Continued*

MONTHLY PROGRESS OF PRESSURE TUNNEL EXCAVATION

Tunnel.	Heading.	Average of Heading and Bench Advance Feet per Month.	Length of Tunnel, Feet.	Date Started.	Date Completed.
Moodna	1S	2, 29, 0, 14, 92, 217, 233, 297, 235, 254, 236, 234, 142	2011	April, 1910	April, 1911
	2N	25, 22, 130, 224, 257, 151, 135, 250, 252, 288, 307, 322	2393	April, 1910	Mar., 1911
	2S	27, 17, 149, 249, 256, 239, 217, 301, 248, 96	1844	April, 1910	Jan., 1911
	3N	24, 11, 75, 183, 172, 202, 204, 213, 267, 219, 95	1701	Mar., 1910	Jan., 1911
	3S	34, 4, 85, 215, 261, 218, 208, 195, 224, 212	1656	Mar., 1910	Dec., 1910
	4N	39, 39, 172, 187, 262, 268, 183, 216, 226, 288, 199	2079	Feb., 1910	Dec., 1910
	4S	33, 45, 174, 183, 316, 296, 192, 254, 206, 249, 225, 229, 112, 0, 0, 3, 5	2522	Feb., 1910	June, 1911
	5N	9, 48, 9, 134, 198, 206, 286, 238, 275, 304, 237, 208, 238, 50	2440	Feb., 1910	Mar., 1911
	5S	11, 42, 13, 144, 183, 201, 268, 267, 282, 240, 188, 205, 239, 51	2334	Feb., 1910	Mar., 1911
	6N	14, 28, 17, 36, 99, 241, 222, 235, 213, 162, 201, 193, 203, 157, 151, 164	2336	Mar., 1910	June, 1911
	6S	9, 41, 13, 34, 111, 209, 199, 246, 218, 171, 154, 204, 199, 164, 179	2151	Mar., 1910	May, 1911
	7N	26, 65, 171, 160, 322, 315, 85	1144	Sept., 1910	Mar., 1911
	7S	39, 48, 182, 168, 0, 0, 0, 6	443	Sept., 1910	April, 1911
Hudson River	West	35, 47, 56, 13, 86, 238, 280, 259, 300, 279, 243, 238, 10	2084	Feb., 1911	Feb., 1912
	East	9, 57, 36, 34, 84, 0, 31, 0, 0, 0, 81, 185, 206, 181, 17	921	Dec., 1910	Feb., 1912
Breakneck	North	7, 44, 80, 131, 86, 108, 214, 75	745	May, 1911	Dec., 1911
Croton Lake	N	27, 23, 0, 0, 13, 79, 124, 118, 115, 127, 105, 168, 183, 195	1277	Nov., 1910	Dec., 1911
	S	17, 77, 0, 0, 23, 54, 101, 99, 111, 108, 123, 98, 153, 187, 180	1332	July, 1910	Dec., 1911
Yonkers	N. portal	27, 187, 104, 97, 66, 102, 113, 110, 26, 149, 135, 62	1178	Sept., 1910	Aug., 1911
	1N	7, 48, 55, 7, 94, 79, 50, 122, 103, 133, 97, 147, 140, 157, 135, 164, 74	1613	July, 1910	Nov., 1911
	1S	7, 56, 50, 2, 93, 73, 45, 126, 111, 133, 103, 178, 186, 179, 117, 0, 35	1494	July, 1910	Nov., 1911
	2N	8, 49, 36, 94, 126, 89, 55, 38, 97, 141, 119, 71, 161, 141, 134, 151, 46	1557	July, 1910	Nov., 1911

	2S	7, 45, 61, 66, 131, 83, 63, 82, 105, 133, 129, 131, 96, 158, 115, 131, 144, 150, 117, 53, 60	2059	July, 1910	Mar., 1912
	3N	35, 57, 12, 74, 86, 69, 135, 112, 131, 127, 107, 139, 131, 74, 111, 100, 120, 53, 0, 0, 0, 0, 0, 25, 44	1740	Aug., 1910	Aug., 1912
	3S	35, 60, 19, 66, 74, 27, 57, 107, 126, 119, 96, 168, 129, 146, 143, 101	1473	Aug., 1910	Nov., 1911
Hill View Reservoir	Uptake N.	37, 21, 0, 54, 109, 139, 106, 159, 162, 125, 221	1184	June, 1910	April, 1911
	Downtake S.	21, 40, 0, 0, 57, 137, 190, 191, 227, 136, 137, 129, 256, 273, 15	1809	July, 1910	Sept., 1911
New York City Tunnel	1N	4, 32, 24, 0, 68, 110, 150, 150, 141, 155, 141, 179, 173		Feb. 3, 1912	
	1S	4, 32, 32, 0, 61, 105, 152, 156, 148, 139, 130, 28, 26		Feb. 3, 1912	
	2N	36, 18, 11, 77, 122, 152, 162, 245, 155, 159, 163, 182, 169		Jan. 9, 1912	
	2S	36, 17, 7, 75, 122, 156, 87, 27, 47, 110, 131, 187, 174		Jan. 9, 1912	
	3N	9, 9, 42, 89, 153, 146, 94, 33, 13, 35, 82, 81, 134, 77, 61		Dec. 8, 1911	
	3S	10, 6, 42, 100, 147, 149, 202, 196, 215, 147, 123, 136, 153, 139, 159		Dec. 8, 1911	
	4N	8, 52, 36, 116, 114, 42, 59, 119, 162, 182, 166, 173, 122		Jan. 30, 1912	
	4S	13, 47, 41, 109, 89, 77, 91, 122, 153, 168, 166, 160, 154		Jan. 30, 1912	
	5N	3, 10, 51, 36, 151, 158, 190, 149, 142, 173, 158, 134, 133		Feb. 7, 1912	
	5S	3, 11, 53, 36, 151, 167, 194, 143, 145, 187, 172, 137, 138		Feb. 7, 1912	
	6N	5, 52, 5, 28, 76, 97, 126, 121, 167, 163, 92, 38		Mar. 4, 1912	
	6S	1, 42, 6, 23, 78, 85, 135, 130, 188, 168, 182, 181		Mar. 7, 1912	
	7N	24, 33, 12, 0, 71, 151, 125, 179, 123		May 22, 1912	
	7S	24, 42, 28, 0, 99, 214, 171, 69, 106		May 22, 1912	
	8N	5, 0, 17, 36, 8, 37, 91, 136, 149, 177, 178		Mar. 19, 1912	
	8S	3, 0, 13, 45, 26, 42, 114, 145, 174, 186, 178		Mar. 21, 1912	
	9N	23, 31, 32, 0, 30, 66, 117, 160, 148		May 13, 1912	
	9S	22, 28, 33, 0, 34, 73, 134, 158, 148		May 14, 1912	
	10N	8, 28, 9, 0, 55, 70, 41, 26, 64, 113, 216, 201		Mar. 8, 1912	
	10S	10, 41, 7, 0, 57, 79, 211, 230, 263, 240, 181, 145		Mar. 8, 1912	
	11N	66, 97, 101, 149, 168, 157		Aug. 17, 1912	

CATSKILL AQUEDUCT—*Continued*

Monthly Progress of Pressure Tunnel Excavation

Tunnel.	Heading.	Average of Heading and Bench Advance. Feet per Month.	Length of Tunnel, Feet.	Date Started.	Date Completed.
New York City Tunnel	11S	70, 107, 96, 131, 155, 129	....	Aug. 20, 1912	
	12N	30, 48, 17, 0, 84, 112, 80, 118, 76, 210, 82	....	Mar. 16, 1912	
	12S	27, 59, 10, 3, 92, 94, 196, 226, 230, 153, 169	....	Mar. 18, 1912	
	13N	0, 0, 0, 70, 40, 149, 171, 176, 131, 185, 229, 264, 229, 0	*1644	Mar. 23, 1912	Jan. 1913
	13S	0, 0, 0, 68, 40, 153, 170, 223, 207, 254, 238, 211, 118, 172, 26	1880	Mar. 23, 1912	Mar., 1913
	14N	41, 11, 29, 100, 172, 162, 237, 198, 219, 193, 208, 220, 247	2037	Dec. 7, 1911	Dec., 1912
	14S	49, 4, 37, 112, 159, 163, 219, 164, 203, 209, 157, 142, 42	1660	Dec. 6, 1911	Dec., 1912
	15N	6, 45, 3, 115, 276, 229, 278, 216, 211, 208, 146, 138, 94	1965	Dec. 14, 1911	Dec., 1912
	15S	9, 29, 21, 128, 232, 226, 274, 155, 229, 217, 152, 142, 195, 23	2032	Dec. 14, 1911	Jan., 1913
	16N	0, 4, 76, 148, 138, 229, 189, 192, 169, 237, 247, 313, 68	2010	Feb. 21, 1912	Jan., 1913
	16S	0, 8, 73, 132, 135, 245, 178, 192, 196, 22	1181	Feb. 21, 1912	Oct. 1912
	17N	18, 50, 56, 120, 192, 194, 172, 75, 96, 89, 44	1106	Dec. 15, 1911	Oct., 1912
	17S	13, 43, 54, 136, 233, 207, 245, 216, 227, 212, 35	1621	Dec. 16, 1911	Oct., 1912
	18N	12, 61, 119, 151, 200, 171, 278, 255, 256, 234, 246, 266, 287, 259, 123	2918	Dec. 20, 1911	Feb., 1913
	18S	12, 78, 115, 143, 196, 187, 264, 255, 238, 222, 249, 247, 285, 270, 257†	*3018	Dec. 21, 1911	Feb., 1913
	19N	32, 118, 5, 169, 239, 208	....	Sept. 21, 1912	
	19S	131, 14, 0, 0, 171, 240, 207	....	Aug. 5, 1912	
	20N	28, 42, 84, 195, 183	....	Oct. 18, 1912	
	20S	27, 47, 85, 150, 231	....	Oct. 17, 1912	
	21N	12	....	Feb., 1913	
	21S	11	....	Feb., 1913	
	22N	58, 102, 39, 254, 278, 253	....	Sept. 19, 1912	
	22S	188, 0, 0, 0, 0, 0, 0, 0, 228, 265, 241	....	Mar. 20, 1912	
	23N	118, 12, 124, 245, 161, 76, 258, 277, 312	....	June 10, 1912	
	24N	108, 6, 201, 259, 142, 223, 271, 283, 233, 6	1732	June 5, 1912	Mar., 1913

* 2 feet beyond contract. † 26 feet beyond contract limit.

BORINGS, TEST PITS, AND SOUNDINGS MADE BY BOARD OF WATER SUPPLY.

Nature of Survey.	Reservoir Department.		Northern Aqueduct Department.		Southern Aqueduct Department.		City Aqueduct Department.*		Long Island Department.		Total.	
	During 1911.	To Dec. 31.	During 1911.	To Dec. 31.	During 1911.	To Dec. 31.	During 1911.	To Dec. 31.	During 1911.	To Dec. 31.	During 1911.	To Dec. 31.
Core Borings,												
River and Lake:												
Number of holes	......	......	......	315	......	19	6	21	......	......	6	355
Depth in water	......	......			......	886	48	558	......	......	48	
Depth in earth	......	......	......	65,546	......	1,234	201	847	......	......	201	71,085
Diamond drill in rock	......	......			......	1,237	......	777	......	......	......	
Total depth †	......	......	......	65,546	......	3,357	249	2,182	......	......	249	71,085
Land:												
Number of holes	......	328	1	36	......	10	22	199	......	......	23	573
Depth in earth, feet	......	20,651	......	2,132	......	570	1,965	17,992	......	......	1,965	84,177
Depth in rock, feet	......	11,769	513	3,997	......	349	5,725	26,717	......	......	6,238	
Total depth †	......	32,420	513	6,129	......	919	7,690	44,709	......	......	8,203	84,177
Grand total †	......	32,420	513	71,675	......	4,276	7,939	46,891	......	......	8,452	155,262
Test-pits:												
Number	......	425	......	936	......	639	18	23	......	......	18	2,023
Total depth	......	3,129	......	......	......	4,321	228	251	......	......	228	7,701
Soundings:												
Number	......	2,269	......	10,139	21	3,443	......	42	......	......	21	15,893
Total depth	......	9,936	......	144,976	229	19,497	......	403	......	......	229	174,812

* Includes surveys reported under Headquarters Department in previous reports.

† Includes borings by Board of Water Supply forces, under contract and by agreement.

RAINFALL IN INCHES—CATSKILL MOUNTAIN WATERSHEDS

Watershed and Station.	1911. Total.	1910. Total.	1909. Total.	1908. Total.	1907. Total.	1906. Total.
Esopus						
Phœnicia	41.04	48.56	45.93	45.13	46.78	44.52
Slide Mountain	48.97	57.82	54.62	50.87	53.45	58.72
Highmount	37.27	40.32	35.55	34.72	41.56	42.82
Edgewood	40.56	48.64	46.43	46.98	52.90	47.85
Lake Hill	42.65	46.71	50.23	46.52	49.25	46.30
Overlook Mountain	41.52	49.18	54.82	46.37		
Kingston	42.43	40.98	41.85	37.18	42.85	
West Hurley	40.07	43.85	46.67	42.05	47.40	
Brown's Station	45.38	45.23	48.79	42.01	47.01	
West Shokan	45.96	51.30	51.76	44.13	50.59	47.91
Moonhaw Lodge	56.49	58.63	62.31	54.80		
Rondout						
Grahamsville	46.55	42.46	44.10	41.73	43.24	44.68
Sundown	42.69	45.25	43.61	40.52	47.07	46.96
Peekamoose	57.19	57.71	56.06	58.71		
Lackawack	41.89	43.75	+39.35	39.19	44.45	42.55
Claryville	46.12	47.09	44.16	44.27	50.23	
High Falls	43.79	39.35	42.77	38.93		
Schoharie						
Windham	28.86	41.14	36.68	36.26	37.98	
Haines Falls	38.38	48.19	47.32	48.51	52.64	
Lexington	30.14	38.72	37.41	32.47	36.94	
Prattsville	30.44	37.01	32.07	28.25		
Catskill						
Preston Hollow	32.41	31.78	34.16	30.81	34.41	
Oak Hill	32.92	33.73	35.38	31.97	36.68	
Franklinton	28.91	31.59	31.49	28.27	37.68	
Westerlo	30.30	31.02	33.11	31.53	35.28	

STREAM FLOW CATSKILL MT. WATERSHEDS

Mean Monthly Discharge in Cubic Feet per Second

Month.	Esopus Creek.											Rondout Creek.							Schoharie Creek.				
	At Esopus Weir. Drainage Area, 239 Square Miles.						At Mt. Marion. Drainage Area, 378 Square Miles.					At Honk Falls. Drainage Area, 105 Square Miles.					At Lackawack Drainage Area, 104 Sq. Miles.		At Prattsville. Drainage Area, 240 Square Miles.				
	1911.	1910.	1909.	1908.	1907.	1906.	1911.	1910.	1909.	1908.	1907.	1910.	1909.	1908.	1907.	1906.	1911.	1910.	1911.	1910.	1909.	1908.	1907.
January	579	1077	811	642	743	....	784	1608	1247	1240	....	354	383	260	251	....	251	....	649	796	628	429	*485
February	349	606	1539	803	202	....	544	678	2824	1323	....	258	680	322	252	†184	210	....	204	802	1220	763	*160
March	548	1704	820	1140	633	....	952	3029	1527	2157	....	725	335	516	359	310	304	....	578	1312	771	992	*648
April	1000	1958	1279	961	543	....	1504	3356	1757	1406	‡836	623	372	468	172	601	484	....	1063	1394	1045	720	*605
May	336	460	838	1567	594	....	406	791	1278	2392	953	....	347	459	172	202	128	246	286	376	674	957	510
June	504	407	388	242	416	....	818	761	661	401	652	....	140	84	119	198	204	142	481	399	291	145	352
July	130	92	78	136	90	....	192	147	138	242	162	....	47	39	23	128	51	39	41	80	51	75	114
August	88	65	106	56	30	....	152	105	168	99	50	....	26	30	19	73	39	38	34	49	37	33	22
September	159	101	57	36	423	....	268	133	99	43	859	....	27	14	149	37	79	70	142	56	27	17	255
October	909	48	56	176	847	§363	1506	76	100	223	1352	....	27	31	279	85	387	34	614	53	30	129	778
November	578	146	42	191	1439	426	936	204	83	243	2177	....	28	38	479	93	276	91	365	311	28	100	1333
December	527	210	158	203	1116	359	824	146	316	239	1681	....	58	72	380	102	273	154	600	337	91	194	1238
The year	476	573	514	528	590	....	739	920	850	834	....	....	206	194	221	....	224	....	422	497	408	380	542

* From United States Geological Survey Record.
† 16 days record.
‡ 27 days record.
§ 13 days record.

LENGTH OF CATSKILL AQUEDUCT IN FEET FROM ASHOKAN RESERVOIR TO TERMINI IN QUEENS BOROUGH AND STATEN ISLAND

Division.	Contract No.	Cut-and-Cover.	Grade Tunnel.	Pressure Tunnel.	Pressure Aqueduct.*	Steel-pipe Siphon.†	Pipe Conduit.	Length of Contract in Division.	Length of Aqueduct in Division.
Reservoir Department									
Olive Bridge	3				588			588	
"	10	3,055			1,237			4,292	4,880
Totals for Department		3,055			1,825				4,880
Northern Aqueduct Department.									
Esopus	11	34,352	3,470					37,822	
"	12	602	3,340	23,608				27,550	
"	62	200				2,755		2,955	68,327
Wallkill	47	20,006	4,010	23,391				47,407	
"	15	15,900						15,900	63,307
Newburgh	16	12,700						12,700	
"	17	‡14,100						14,100	
"	18	15,600						15,600	
"	45	28,190						28,190	
"	62	100				3,267		3,367	73,957
Hudson River	20	395		25,200				25,595	
"	90			3,022				3,022	

Hudson River	80	710	§ 1,080	793				2,583	
"	22	2,362	5,365					7,727	
"	62	1,777				3,737		5,514	44,441
Peekskill	2	41,851	14,680					56,531	
"	62	1,635				9,310		10,945	67,476
Totals for Department		190,480	31,945	76,014		19,069			317,508
Southern Aqueduct Department.									
Croton	23	5,445	6,450					11,895	
"	24	2,118	1,400	2,639				6,157	
"	25	13,248	3,700					16,948	
"	55	14,539	15,430		1,035			31,004	
"	68	512				3,652		4,164	70,168
Kensico	55	250	4,316		14,560			19,126	19,126
White Plains	52	14,502	8,725		391			23,618	
"	53	24,437			138			24,575	
"	68	307				4,346		4,653	52,846
Hill View	54			‖ 11,178				11,178	
"	30			2,999	2,859			5,858	
"	68	52				5,571		5,623	22,659
Totals for Department		75,410	40,021	16,816	18,983	13,569			164,799

Cut-and-cover extends to center lines of end shafts of pressure tunnels and includes chambers at ends of steel-pipe siphons, Kensico influent chamber and part of the filter connection chamber.

Pressure tunnel is measured from center lines of end shafts.

* Includes special structures in the head works, reinforced concrete siphons, Venturi meters, Hill View by-pass, and all aqueduct structures in open cut between Kensico influent chamber and filter connection chamber.

† Horizontal lengths.

LENGTH OF CATSKILL AQUEDUCT IN FEET FROM ASHOKAN RESERVOIR TO TERMINI IN QUEENS BOROUGH AND STATEN ISLAND—*Continued*

Division.	Contract No.	Cut-and-Cover.	Grade Tunnel.	Pressure Tunnel.	Pressure Aqueduct.	Steel-pipe Siphon.	Pipe Conduit.	Length of Contract in Division.	Length of Aqueduct in Division.
City Aqueduct Department.									
Bronx	63	....	....	21,260	....	....	....	21,260	
"	65	....	....	28,300	....	....	....	28,300	49,650
Manhattan	66	....	....	23,120	....	....	....	23,120	
"	67	....	....	21,150	....	....	....	21,150	44,270
Conduit and reservoir	87	....	....	....	....	....	17,084	17,084	
" "	75	....	....	....	....	....	16,293	16,293	
" "	¶ 99	....	....	....	....	....	9,830	9,830	
" "	¶ 88	....	....	....	....	....	10,000	10,000	
" "	¶ 86	....	....	....	....	....	12,448	12,448	
" "	103	....	....	....	....	....	20,824	20,824	86,479
Totals for Department	....	....	....	93,830	....	....	86,479	....	180,309
Grand totals	....	268,945	71,966	186,660	20,808	32,638	86,479	....	667,496

‡ Includes St. Elmo reinforced concrete siphon.
§ Includes siphon chamber at south portal of Breakneck tunnel.
|| Includes connection chamber at north end of Yonkers pressure tunnel.
¶ Not awarded to December 31, 1911.

LIST OF PUBLISHED ARTICLES ON THE ENGINEERING FEATURES OF THE CATSKILL WATER SYSTEM

GENERAL DESCRIPTIVE

"N. Y. City Water Supply." By W. W. Brush, Dept. Engr., Board of Water Supply, N.E.W.W. As Soc. Journal, Dec., '09. Abstract of paper Engr. Rec. Sept. 18, 1909.

"World's Greatest Aqueduct." By A. D. Flinn, Dept. Engr., Board of Water Supply, Century Mag., Sept., '09.

"Catskill Water System of New York City." By P. C. Barney, Prin. Asst. Engr., Board of Water Supply, Proc., Brooklyn Engineers' Club, 1910.

"N. Y. City's Additional Water Supply from Catskill Mountains." By T. H. Wiggin, Senior Designing Engr., Board of Water Supply, Proc. Engineers' Club of Phila., July, 1911.

"A Subway for Water." By Earnest Hamlin Abbott, The Outlook, Jan. 23, 1909.

"Catskill Waterworks and Ashokan Reservoir Dams." Eng. News, May 9, 1907.

"The New York Water Supply." Abstract of a report by J. Waldo Smith, Chief Engr. Board of Water Supply, Engr. Record, current news, Oct. 14, 1905.

"Details of the Catskill Aqueduct, New York." Eng. Rec., Nov. 10, 1906.

"Floor Area Unit as a Basis for Estimating Water Consumption." By W. W. Brush, Dept. Engr., Board of Water Supply. Eng. News., June 13, 1912. Eng. Rec., June 15, 1912.

"Catskill Water System of the City of New York." By H. P. Kieffer, Engng. (London), July 28, 1911.

"A Gigantic Engineering Undertaking." By Fred F. Moore, Designing Engr., Board of Water Supply, Science Conspectus, Mar., 1912.

SURVEYING

"Methods Used in Preliminary Work on Catskill Aqueduct." By J. S. Langthorn, Divn. Engr., Board of Water Supply, Proc. Brooklyn Engr. Club, No. 79, 1908.

"Bench Levels and N. Y. City Datums." By C. Goodman, Asst. Engr., Board of Water Supply, Proc. Mun. Engrs. of the City of N. Y., 1908. Eng. Rec., Oct. 3, 1908.

"Stadia Surveys. Catskill Aqueduct." By Boris Levitt, Asst. Engr., Board of Water Supply. Eng. News, Sept. 3, 1908.

"Bench Level Operations on the Catskill Aqueduct Line." By M. E. Zipser, Asst. Engr., Board of Water Supply, Eng. News, Feb. 20, 1908.

GEOLOGICAL INVESTIGATION

"Some Geological Features Affecting the Catskill Water Supply." By J. F. Sanborn, Asst. Engr., Board of Water Supply, Harvard Engng. Jour., June, 1908.

"Subsurface Investigation—Catskill Aqueduct." By R. Ridgway, Dept. Engr., Board of Water Supply, Eng. Rec., April 18, 1908. Eng. Rec., April 25, 1908.

"Core Drilling under the Hudson River for the Catskill Aqueduct." By W. E. Swift, Div. Engr., Board of Water Supply, Eng. News, Apr. 7, 1910.

"Studies and Explorations for the Hudson River Crossing of the Catskill Aqueduct." By S. D. Dodge and W. B. Hoke, Asst. Engineers, Board of Water Supply, Proc. Mun. Engr. of N. Y., 1910. Eng. Rec., April 25, 1908. Eng. Rec., Oct. 8 and 15, 1910.

"Geological Problems Presented by the Catskill Aqueduct of the City of New York." By J. T. Kemp, Consulting Geologist, Board of Water Supply, Qr. Bul. of Can. Min. Inst., Oct. 5, 1911.

"Geology of the New York City (Catskill) Aqueduct." By Chas. P. Berkey, Consulting Geologist. Board of Water Supply, N. Y. State Museum Bul. No. 146, 1911.

"Testing Diamond Drill Borings at the Site of the Olive Bridge Dam, Ashokan Reservoir." Eng. Rec., July 4, 1908.

"California Stove-Pipe Wells of Long Island." Describes the method of driving these wells and the outfit used. Eng. Rec., Feb. 29, 1908.

"Geology of New York City in its Relation to Engineering Problems." By Chas. P. Berkey, Consulting Geologist, Board of Water Supply, and John R. Healy, Asst. Engr., Board of Water Supply. Proc. Mun. Engrs. of the City of N. Y., 1911.

"Quarries, Ashokan Reservoir Stone Quarry." Eng. Rec., Apr. 2, 1910.

"Quality of Bluestone in the Vicinity of the Ashokan Dam." By Chas. P. Berkey, Consulting Geologist, Board of Water Supply. Col. Sch. of Mines Qr., Jan., 1908.

"Inclined Diamond-drill Borings under the Hudson River." Eng. Rec., Jan. 15, 1910.

"Deep Inclined Diamond-drill Borings. Hudson River Crossing. Catskill Aqueduct." Engr. Rec., Apr. 2, 1910.

"Bore Holes." Determining the direction of deep bore holes and testing their watertightness. Illustrates and describes an instrument devised by John J. Horan, Asst. Engr., Board of Water Supply, for use in connection with the work of building the great aqueduct that is to carry additional water to New York City. Engr. News, May 23, 1907.

"The Storm King Crossing of the Hudson River by the New Catskill Aqueduct of New York City." By J. F. Kemp. Amer. Journal of Science, July, 1912.

"Subsurface Investigation Catskill and Long Island Aqueducts." Robt. Ridgway, Dep. Engr.; W. E. Spear, Dep. Engr.; W. Fitch Smith, Div. Engr., and D. S. Mallett, Asst. Engr., Board of Water Supply. Proc. Mun. Engrs., City of N. Y., 1908.

CONSTRUCTION—GENERAL

"Tunnel Lining, Catskill Aqueduct." By M. E. Zipser, Asst. Engr., Board of Water Supply, Eng. News, May 2, 1912. Eng. Mag., July, 1912.

"Grouting the Concrete Lining of the Rondout Pressure Tunnel." By R. L. Wittstein, Asst. Engr., Board of Water Supply, Eng. Rec., Dec. 30, 1911.

"Rye Outlet Bridge at Kensico Reservoir, Concrete Arch Bridge." Eng. Rec., Oct. 14, 1911.

"A Large Timber Bulkhead under 168 Feet Head." By A. W. Tidd, Asst. Engr., Board of Water Supply, Eng. News, July 25, 1912.

"Methods of Alignment in Three Pressure Tunnels." Yonkers Pressure Tunnel: By Jas. L. Davis, Asst. Engr., Board of Water Supply. Van Cortlandt Siphon: By Edward A. May, Asst. Angr., Board of Water Supply. Wachusett Aqueduct Tunnel: By A. W. Tidd, Asst. Engr., Board of Water Supply. Eng. News, June 20, 1912.

"The Removal of Entrained Air from the Catskill Aqueduct." Eng. Rec., Aug. 3, 1912.

"Method of Trussing Concrete Forms." By Arnold Becker, Eng. Rec., Nov. 25, 1911.

"Meeting of the Headings of the Catskill Water Supply Tunnel." Eng. News, Feb. 15, 1912.

"Catskill Aqueduct." Eng. Rec., Jan. 3, 1910.

"Esopus Section." Eng. Rec., Nov. 5, 1910.

CONSTRUCTION—RESERVOIRS AND DAMS

"Masonry Dam Formulas, Series of Formulas Deduced in Connection with Studies made for the Board of Water Supply." By O. L. Brodie, Asst. Engr., Board of Water Supply, Col. Sch. of Mines Qr., Apr. 1908.

"Dams for Catskill Water Works." By A. D. Flinn, Dept. Engr., Board of Water Supply Harvard Engr. Journal, Nov., 1909.

"NEW KENSICO DAM." By A. D. Flinn, Dept. Engr., Board of Water Supply. Eng. News, Apr. 25, 1912.

"ASHOKAN RESERVOIR." Specifications for the main dam. Gives sections from specifications with explanatory notes, Eng. News, Aug. 1, 1907.

"CONSTRUCTION OF PRESSURE AQUEDUCT, ASHOKAN RESERVOIR." Eng. Rec., July 12, 1911.

"HILL VIEW RESERVOIR, PLAN, SECTION AND BRIEF DESCRIPTION," Eng. Rec., Dec. 18, 1909.

"KENSICO RESERVOIR." Eng. Rec., Dec. 25, 1909.

"GROUTING THE OLIVE BRIDGE DAM," Eng. Rec., April 8, 1911.

"SOIL STRIPPING." Is it worth while to strip the surface soil from Ashokan reservoir sites? Abstract by Hazen and Fuller. Eng. News, Jan. 3, 1907.

"HILL VIEW RESERVOIR." Features of the design, provisions for housing and feeding laborers and horses, dump carts, cars, stone crushers, etc. Mun. Jour. and Engr., August 3, 1910.

"CONSTRUCTION OF WASTE WEIR AT ASHOKAN RESERVOIR." Eng. Rec., July 22, 1911.

CONSTRUCTION—SHAFTS

"SHAFT SINKING—RECORD MADE—MOODNA SIPHON." March 3–April 3, 1910. Eng. Rec., April 16, 1910.

"SHAFT SINKING—RECORD—(CATSKILL AQUEDUCT)." Eng. Rec., Apr. 15, 1911.

"SOME INTERESTING CASES OF SHAFT SINKING." By John S. Franklin, Cassier's Magazine, Feb., 1912.

"RAPID SHAFT SINKING IN HARD ROCK. EAST SHAFT HUDSON TUNNEL." Eng. News, April 13, 1911. Eng. Rec., April 15, 1911.

"SHAFT SINKING, CATSKILL AQUEDUCT." By F. Donaldson, Mines and Minerals, April, 1909.

"SINKING A WET SHAFT." By J. P. Hogan, Asst. Engr. Board of Water Supply, Am. Soc. C.E. Proc., March, 1911 (Abstract), Eng. Rec., April 8, 1911.

"RONDOUT SIPHON, LINING THE UPTAKE SHAFT." By H. L. Wittstein, Asst. Engr., Board of Water Supply, Eng. Rec., March 11, 1911.

CONSTRUCTION—PRESSURE TUNNEL

"MOODNA PRESSURE TUNNEL." Eng. Rec., June 4, 1910.

"RONDOUT PRESSURE TUNNEL LINING." Eng. Rec., Sept. 17, 1910.

"WALLKILL PRESSURE TUNNEL." Eng. Rec., Apr. 2, 1910.

"WALLKILL PRESSURE TUNNEL EXCAVATION." By C. R. Hulsart, Asst. Engr., Board of Water Supply, Eng. News, Oct. 20, 1910.

"TEST OF WATERTIGHTNESS OF CONCRETE TUNNEL LINING UNDER HIGH HEAD." (Wallkill Pressure Tunnel.) By C. R. Hulsart, Asst. Engr., Board of Water Supply. Eng. News, Dec. 14, 1911.

"Holing through the Hudson Crossing Tunnel." Eng. News, Feb. 1, 1912. Eng. Rec. Current News Suppl., Feb. 3, 1912.

"Hudson River Crossing of the Catskill Aqueduct." By R. Ridgway, Dept. Engr., Board of Water Supply, N.E.W.W. Assn. Journal, Sept., 1911.

"The Deepest Siphon Tunnel in the World." By R. K. Tomlin, Jr., Scribner's Magazine, May, 1912.

"Construction of the Rondout Pressure Tunnel of the Catskill Aqueduct." By L. White, Div. Engr., Board of Water Supply. Proc. Mun. Engrs. of the City of N. Y., 1911.

"Hudson Tunnel of the Catskill Aqueduct for Water Supply of N. Y. City." By A. D. Flinn, Dept. Engr., Board of Water Supply. Eng. News, Mar. 23, 1911.

"Design of Pressure Tunnels of the Catskill Aqueduct." By T. H. Wiggin, Sen. Des. Engr. Board of Water Supply, Eng. Rec., Jan. 29, 1910. Abstracts, Eng. Rec., Feb. 5, 1910. Proc. Mun. Engrs. of the City of N. Y., 1909.

"Rondout Pressure Tunnel." By A. D. Flinn, Dept. Engr., Board of Water Supply, Eng. News, June 1, 1911.

"Rondout Pressure Tunnel. Driving a Wet Aqueduct Tunnel in Hard Rock." By B. H. Wait, Asst. Engr., Board of Water Supply. Eng. Rec., June 17, 1911.

"Deep Tunnel Alignment." By H. M. Hale, Asst. Engr., Board of Water Supply, Harvard Eng. Jour., Nov., 1910. Eng. Rec., Jan. 14, 1911.

CONSTRUCTION—GRADE TUNNEL

"Lining a Part of the Bonticou Grade Tunnel. Methods Followed on a 17×13 Ft. Rock Tunnel on the Catskill Aqueduct." By John H. C. Gregg, Eng. Rec., June 22, 1912.

"A Compressed Air Tunnel Driven without a Shield through Wet Earth at East View." Eng. Rec., July 20, 1912.

"Tunneling in Wet Earth." Eng. Rec., July 20, 1912.

"Soft Ground Tunneling without Compressed Air on the Catskill Aqueduct." By Chester M. Gould, Asst. Engr., Board of Water Supply. Eng. Rec., Aug. 10, 1912.

"Hunter's Brook Tunnel Construction." Eng. Rec., April 2, 1910.

"Hunter's Brook Tunnel Cave." Eng. Rec., March 18, 1911.

"Hunter's Brook Tunnel, Bottom Heading." Eng. Rec., Sept. 23, 1911.

CONSTRUCTION—CITY AQUEDUCT TUNNEL AND PIPE LINES

"Under-City Tunnel for Delivering Catskill Water to the Distribution Mains, N. Y. City." By A. D. Flinn, Dept. Engr., Board of Water Supply. Harvard Eng. Jour., Jan., 1911.

"New Water Supply Tunnel under N. Y. City." Eng. News, May 11, 1911.

"Progress on City Tunnels." By W. E. Spear, Dept. Engr., Board of Water Supply, Proc. Mun. Engrs. of N. Y., 1912.

"Water Supply Tunnel beneath the East River." Eng. News, July 7, 1910.

"Proposed Delivery System of the Catskill Water Supply." Eng. Rec., Dec. 11, 1909. Eng. News, Dec. 9, 1909. Eng. News, June 2, 1910.

"New Water Supply Tunnel under New York City." Eng. News, May 11, 1911.

"City Aqueduct to Deliver Catskill Water Supply to the Five Boroughs of Greater New York." By W. W. Brush, Dept. Engr., Board of Water Supply, Proc. Brooklyn Engrs. Club, 1910.

"Ship's Anchors and Submerged Pipe Lines." (Narrows' Pipe Line). Eng. Rec., Dec. 9, 1911.

"Motor Trucks for Hauling Blasted Rock from City Aqueduct Tunnel, N. Y." Eng. Rec., March 30, 1912.

CONSTRUCTION—STEEL AND REINFORCED CONCRETE PIPE

"Foundry Brook." Eng. Rec., April 15, 1911.

"Protection of Steel Pipes, Catskill Aqueduct." By A. D. Flinn, Department Engr., Board of Water Supply, N.E.W.W. Assn. Journal, Sept. 1911. (Abstract) Eng. Rec., Sept. 16, 1911. Eng. News, Nov. 2, 1911.

"Handling Large Steel Pipes in the Trench by a Novel Method." By Chas. H. Howe, Eng. Rec., Oct. 14, 1911.

"Aqueduct Construction at Ashokan Reservoir, Contract 10." Eng. Rec., April 22, 1911.

"Kensico By-Pass Aqueduct Construction." By H. W. Nelson. Eng. Rec., April 1, 1911.

CONSTRUCTION CUT-AND-COVER

"Cut-and-cover Aqueduct of New York Additional Water Supply." By A. D. Flinn, Dept. Engr., Board of Water Supply, Worcester Polytechnic Inst. Jour., March, 1911.

"Design of Large Conduits in Open Cut, Concrete Section." Eng. Rec., Oct. 28, 1911. Assn. Eng. Soc., Journal, Sept., 1911.

CONTRACTORS' PLANTS

"Construction Plant Employed on the N. Y. Water Supply." By H. P. Kieffer, Mun. Engr., August, 1909.

"Use of Electricity on the Catskill Aqueduct." Elec. World, March 2, 1911.

"Concrete Plant—Olive Bridge Dam." Eng. Rec., April 3, 1909.

"Methods of Construction and Contractor's Plant on the Ashokan Reservoir." Engr. Contg., Oct. 19, 1910.

"Compressed Air Plant for the Rondout Siphon." Eng. Rec., Apr. 10, 1910.

"Large Portable Plant for Crushing, Mixing and Placing Concrete on Catskill Aqueduct." Engng. Contg., Dec. 7, 1910.

"Steam Rollers used in the Construction of the Earth Dams of the Ashokan Reservoir." Eng. News, Oct. 21, 1909.

"Compressed Air Plant, Contracts 12 and 54." By F. Richards, Eng. News, April 20, 1911.

"Air Compressor Plant for Driving the Moodna Siphon on the New York Aqueduct." (Abstract.) Eng. News, Feb. 23, 1911.

"Rock Crushing Plant, Kensico Dam." By S. W. Traylor, Eng. News, Feb. 22, 1912. Eng. Rec., Feb. 24, 1912.

CONTRACTORS' CAMPS—SANITATION

"Sanitary Problems on the Catskill Aqueduct Work." Eng. Rec., May 6, 1911.

"The Contractor's Camp at the Ashokan Reservoir." Eng. Rec., March 25, 1911. Correction, April 8, 1911.

"Construction Camps—N. Y. State Barge Canal and N. Y. City's New Aqueduct." The Survey, Vol. 23, No. 14, Jan. 1, 1910.

"Sanitation in Construction Camps of the Catskill Aqueduct." Eng. Rec., April 2, 1910.

"Housing Conditions and Wages on the N. Y. State Barge Canal and on the Ashokan Dam, Board of Water Supply, New York City." Eng. News, Aug. 5, 1909.

"The Sanitation of Contractor's Camps and the Patrol of Watersheds. Sanitation of Contractor's Camps, N. Y. C. Water Supply." By A. J. Provost, Sanitary Expert, Board of Water Supply, Proc. Assoc. Eng. Soc., March, 1912.

"Sanitary Problems of the Catskill Aqueduct." By David S. Flynn, M. D., Sanitary Inspector, Board of Water Supply, Proc. Eng. Club, Philadelphia, Oct., 1911.

"Protection of New York's Water Supply from Pollution During Construction Work." By A. J. Provost, Sanitary Expert, Board of Water Supply, N.E.W.W. Association Jour., Sept., 1911.

"Sanitary Problems of the B. W. S." By A. J. Provost, Sanitary Expert, Board of Water Supply, Proc. Mun. Engrs. of the City of New York, 1911.

MISCELLANEOUS

"The Organization of an Engineering Force." By A. D. Flinn, Dept. Engr., Board of Water Supply. Proc. Mun. Engr., 1906. (Abstract.) Eng. Rec., Sept. 29, 1906.

"Filing and Indexing System of the Board of Water Supply." By A. D. Flinn, Dept. Engr., Board of Water Supply. Jour. Assoc. Engn. Soc., Oct., 1909.

"Filing and Indexing System of the Board of Water Supply." By J. Leo Murphy, Asst. Engr., Board of Water Supply. Eng. News, Aug. 6, 1908.

"Drafting Methods of the Board of Water Supply." By C. F. Bell, Asst. Engr. in Charge of Drafting, Board of Water Supply. Proc. Mun. Engrs. of the City of N. Y., 1912. Eng. Rec., April 6, 1912.

"Permeability of Concrete and Solubility of Aggregates. Tests Made During 1909 by the Board of Water Supply." Eng. Rec., Jan. 21, 1911.

"A 250-ton Hydraulic Compression Testing Machine." By J. L. Davis, Asst. Engr., Board of Water Supply, Eng. News, Feb. 11, 1909.

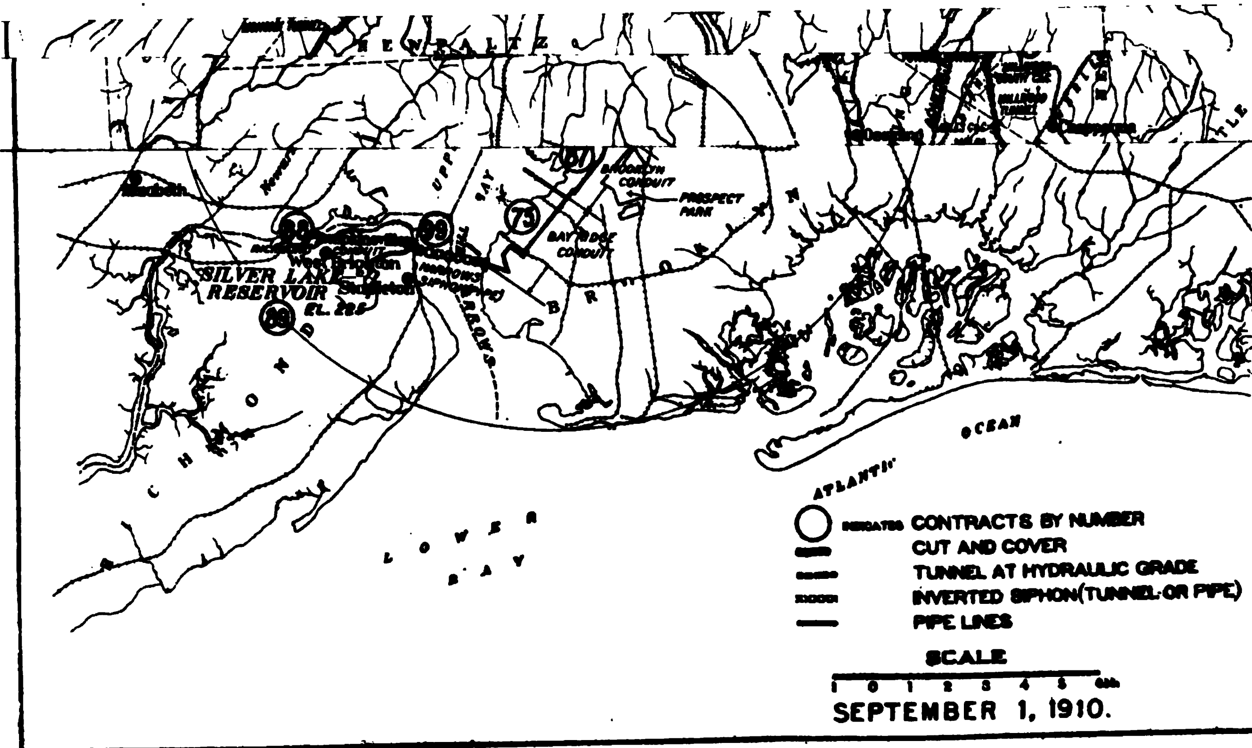
"Investigations of Impermeable Concrete by the Laboratory of the Board of Water Supply, N. Y. C." By J. L. Davis, Asst. Engr., Board of Water Supply, Engng. Contg., Feb. 26, 1908.

"Sluice Gates and Valves for the Catskill Waterworks." Eng. Rec., Sept. 9, 1911.

"Catskill Aqueduct Control Valves." By James Owen, Eng. News, Feb. 1, 1912.

"Venturi Meters. How the Flow of Water through the Catskill Aqueduct Will be Measured. Description of the Three Largest Venturi Meters Ever Constructed and Apparatus for Making Continuous Records of the Flow." Eng. Rec., Jan. 20, 1912.

"Aerator Nozzle Tests for Catskill Water Supply." Eng. Rec., Dec. 2, 1911.



MAP OF CATSKILL WATERWORKS

BOARD OF WATER SUPPLY
CITY OF NEW YORK.

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